2021 Conference on Implantable Auditory

July 12-16, 2021
Virtual Conference

V2.1

2021 CONFERENCE ON IMPLANTABLE AUDITORY PROSTHESES

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How to Navigate the CIAP 2021 meeting and website

There are four main rooms at the conference site at https://ciap2021.vfairs.com/. Once you log in you will be in the Lobby, in which you will see a menu bar across the top, as well as clickable banners to the three main meeting rooms: the Auditorium, the Poster Hall, and the Lounge. You may also get help and technical support by clicking on the Information Desk. Click on the signs beside the desk for help with text and video chats and the Poster Hall.

Live talks and sessions will occur in the Auditorium at the times listed in the program (see a summary of live talks by clicking on the screen in the Auditorium). Each day will have live talks at either 7am-8:30am Tahoe (California) time or at 14:00-15:30 or both. A live Q&A session will occur immediately after each live talk.

Pre-recorded Invited talks, Featured Recorded talks, and posters are all available in the Poster Hall. Select the topic area of interest from the pull-down menu at the top bar. Recorded talks and posters will appear as a sideways scrollable list. Each item will have multiple parts: a video, the abstract, a pdf of posters, possibly a downloadable handout, and a chat session for Q&A. Each item will also list when the author will be available for a live Question/discussion period.

Each day will have three live time periods for questions for pre-recorded talks and posters. Speakers and Authors will post the time they will be available to answer questions on their talk or poster. Go to the poster hall and click on the link provided in the talk or poster at the listed times and you will go to a video session (on the Whereby platform) with the author.

The Lounge is a place for conversations, either about science or simply for social chats. Topical discussions are listed at the left of the hall and social groups are listed on the right side. When you click on a link you will enter a breakout room with live discussions via the app Whereby.

Live talks and their Q&A sessions will be recorded and available on the vfairs site until mid-August.
Prerecorded talks and posters will remain accessable on the vfairs site for the entire meeting, and for one month after the meeting.
All recorded and print materials will be available after August on the CIAP home website: CIAPHome.org.
During the meeting Conference information and technical help can be obtained by clicking on the Information desk in the Lobby.

CIAP 2021 Program Overview

Note: All times listed are in Tahoe Time (PST: GMT-8)

Monday, July 12

7:00-8:30 Machine-learning and AI: Applications to hearing diagnosis and devices
14:00-15:30 Understanding the nerve & brain's response to CI stimulation: Peripheral & Central Physiology

Monday Q&A sessions for Invited and Featured Recorded Talks and Posters
2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall
Topics: Machine Learning, Physiology, Auditory Modeling

Tuesday, July13

7:00-8:30 Mentoring Session
14:00-15:30 Company Session

Tuesday Q&A sessions for Invited and Featured Recorded Talks and Posters
2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall
Topics: Child Development, Psychophysics, Speech Perception

Wednesday, July 14

7:00-8:30 Neural rhythms
8:30 Nominating Candidates for 2023 CIAP Chair and Co-Chair – Election Instructions
12:15-13:45 Virtual Music Night Event: https://dbsplab.fun/k/ciap2021.php
14:00-15:30 Auditory attention and learning, and device evaluations in real-world listening conditions

Wednesday Q&A sessions for Invited and Featured Recorded Talks and Posters
Auditory attention and learning,
2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall
Topics: Neural Rhythms, Attention, Cognition and Effort, Auditory Plasticity and Training, Outcomes and Predictive Factors
Device technology developments & central auditory prostheses

Thursday, July 15

14:00-15:30

Thursday Q&A sessions for Invited and Featured Recorded Talks and Posters
2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall
7:00-8:30 Binaural/bilateral/bimodal hearing, devices and signal processing
Topics: Device Technology, Signal Processing
8.30 Closing session (end of live talks, but recorded talks, posters and Q&A sessions continue until 18:00)

Friday, July 16

Friday Q&A sessions for Invited and Featured Recorded Talks and Posters
2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall
Topics: Bilateral, Binaural, Bimodal, EAS Stimulation, Music and Pitch

CIAP 2021 Session Times

Live talk session times

Morning ("Tahoe time") session

	Los Angeles	New York	London	Paris	Beijing	Melbourne
Start	7:00am	10:00am	3:00pm	4:00pm	10:00pm	+12:00am
End	8:30am	11:30am	4:30pm	5:30pm	11:30pm	+1:30am

Afternoon ("Tahoe time") session

	Los Angeles	New York	London	Paris	Beijing	Melbourne
Start	2:00pm	5:00pm	10:00pm	11:00pm	+5:00am	+7:00am
End	3:30pm	6:30pm	11:30pm	+12:30am	+6:30am	+8:30am

Short-talk (pre-recorded, invited and featured) and poster discussion session times

Europe/Africa - Asia/Pacific Session

	Los Angeles	New York	London	Paris	Beijing	Melbourne
Start	2:00am	5:00am	10:00am	11:00am	5:00pm	7:00pm
End	3:00am	6:00am	11:00am	12:00pm	6:00pm	8:00pm

Americas - Europe/Africa Session

	Los Angeles	New York	London	Paris	Beijing	Melbourne
Start	11:00am	2:00pm	7:00pm	8:00pm	+2:00am	+4:00am
End	12:00pm	3:00pm	8:00pm	9:00pm	+3:00am	+5:00am

Americas – Asia/Pacific Session

	Los Angeles	New York	London	Paris	Beijing	Melbourne
Start	5:00pm	8:00pm	+1:00am	+2:00am	+8:00am	+10:00am
End	6:00pm	9:00pm	+2:00am	+3:00am	+9:00am	+11:00am

Monday July 12

Note: All times listed are in Tahoe Time (PST: GMT-8)

Machine-learning and AI: Applications to hearing diagnosis and devices

https://youtu.be/mlV9WbcEm94

Live Session (S) chairs: Julie Arenberg and Piotr Majdak

7.00	**Ian & Astrid**	*Introduction and Overview of the Conference, Logistics*
7.10	**Waldo Nogueira (S)**	*Opportunities and challenges for machine learning in auditory implants*
7.30	**Nima Mesgarani (S)**	*Brain-controlled assistive hearing technologies: Challenges and opportunities*
8.00	**Jing Chen (S)**	*Detection of auditory attended object in congruent audiovisual scenario*

Machine-learning and AI: Invited (I) and Featured (F) Recorded Talks

Simon Doclo (I)	*Cognitive-driven binaural beamforming for hearing devices using EEG-based auditory attention decoding* *https://youtu.be/mGZxoU_XWTU*
Ariel Edward Hight (F)	*Genetic algorithms for optimizing acoustic models of cochlear implant hearing in SSD-CI subjects* *https://youtu.be/sgt_CXbDroM*

Understanding the nerve & brain's response to CI stimulation: Peripheral & Central Physiology

https://youtu.be/RGBeE00lUO0

Live Session (S) chairs: Lina Reiss and Blake Butler

14.00	**Magriet van Gendt (S)**	*Understanding intracochlear electrocochleography with a computational model* *https://youtu.be/p8u6rwgkAOM*
14.30	**Charlie Liberman (S)**	*Auditory nerve degeneration in humans and the effects of cochlear implantation*
15.00	**Colette McKay (S)**	*What physiological differences underlie variation in speech perception benefit for CI users?* https://www.youtube.com/watch?v=t_N6p_S5YhI

Physiology: Invited (I) and Featured (F) Recorded Talks

Ben Somers (I)	*Neural tracking of the speech envelope in cochlear implant users* *https://youtu.be/Kl0xDRzFmHk*
Andrej Kral (I)	*Cortical oscillations reveal loss of top-down interactions following congenital deafness* *https://youtu.be/nwSuaiDE__s*
Robin Davis (I)	*Voltage-gated ion channels tune the kinetics and sensitivity of spiral ganglion neurons* *https://youtu.be/9DMLJho3M-Y*
Wiebke S Konerding (F)	*Electrophysiological changes after focal spiral ganglion neuron lesions* *https://youtu.be/p5mR0TVKq3s*

Auditory Modeling: Invited (I) and Featured (F) Recorded Talks

Tania Hanekom (I)	*3D current spread and neural modelling of human cochleae* *https://youtu.be/iEHTWLIYi_A*
Tim Brochier (F)	*Comparing phonemic information transmission with cochlear implants between human listeners and an end-to-end computational model of speech perception* *https://youtu.be/Xml_TYfVBAE*

Tuesday 13 July

7:00-8:30 Mentoring Session, Moderator: Ruth Litovsky

Breakout Room Topics covered in all rooms:

1. *How were careers, opportunities and work relationships impacted by the pandemic?*
2. *Career options and decisions about academic settings, industry and government.*
3. *Navigating career transitions while considering teaching, research and service.*
4. *Supporting our research and productivity: managing grants and publications*

Group 1: Karen Gordon, Kelly King, Rene Gifford, Ian Bruce

Group 2: Astrid van Wieringen, Josh Bernstein, Mario Svirsky, Matt Winn

Group 3: Monita Chatterjee, Sara Duran, Blake Butler, Ellen Peng

Group 4: Denis Baskent, Roger Miller, Matt Goupell, Julie Arenberg

Group 5: Liat Kishon Rabin, Dan Gnansia, Lina Reiss, Smita Agrawal, Vasant Dasika

14:00-15:30 Company Session, Moderator: Bob Shannon

Advanced Bionics
Cochlear
MedEl
Oticon

Child Development: Featured (F) Recorded Talk

Elizabeth Pierotti (F) *An electrophysiological study of audiovisual speech perception in CI-using deaf children* https://youtu.be/2--lG-Cy9Pg

Psychophysics: Featured (F) Recorded Talk

Soha Garadat (F) *Estimating health of the implanted cochlea using psychophysical strength-duration functions and electrode configuration* https://youtu.be/okoOLEkF0Cw

Speech perception- Featured (F) Recorded Talks

Arefeh Sherafati (F) *Dorsolateral prefrontal cortex supports spoken word recognition in listeners with cochlear implants: Evidence from high-density diffuse optical tomography* https://youtu.be/-w4A1aGlxWc

Brittney L. Carter (F) *Effects of neural adaptation and adaptation recovery on word recognition in cochlear implant users* https://youtu.be/_0-VjYF2dJ4

From vibrations in the ear to abstractions in the head

Wednesday 14 July

Neural rhythms https://youtu.be/Zi_Dd5Tg0eA

Live Session (S) chairs: Michelle Hughes and Jan Wouters

7.00 David Poeppel (S)

7.30 Robin Gransier (S) *Rate and envelope encoding in the electrically-stimulated auditory pathway*

8.00 Debi Vickers (S) *Relating sound-evoked brain responses to aspects of speech Understanding for cochlear implant users*

Sumit Agrawal (I) *Synchrotron imaging of the inner ear*

Evoked Potentials and Imaging: Invited (I) and Featured (F) Recorded Talks

https://youtu.be/YJJR8BMTpBk

Wanting Huang (F) *Fundamental frequency processing in mandarin-speaking children with cochlear implants as revealed by the peak latency of positive mismatch response (P-MMR)* https://youtu.be/-El29J3S7Bo

Virtual Music Night Event (Don't Miss!!)

Please join this session on YouTube Live: https://dbsplab.fun/k/ciap2021

12.15 – 13:45

Auditory attention and learning, and device evaluations in real-world listening conditions
https://youtu.be/reMhcdGencc

Live Session (S) chairs: Jill Firszt and Deniz Baskent

14.00 Barb Shinn-Cunningham (S) *Effects of distraction on processing and storing sound streams*

14.30 Brandon Paul (S) *Neural correlates of multi-talker listening in cochlear implant users*

15.00 Shyanthony Synigal (S) *Indexing the acoustic and linguistic processing of natural speech using low- and high-frequency EEG* https://youtu.be/ajpAzJuLnm8

Attention, Cognition and Effort: Invited (I) and Featured (F) Recorded Talks

Nina Aldag (F) *Towards decoding selective attention in unilaterally deafened subjects using cochlear implant electrodes as sensors* https://youtu.be/Y9fQr9G2tZk

Rachael J. Lawrence (F) *Examining executive function and its relationship with language outcomes in paediatric cochlear implant recipients: A behavioural and functional near-infrared spectroscopy (FNIRS) study* https://youtu.be/whYmVsIvwtY

Rebecca S. Benjamin (F) *Examining the use of an auditory balance prosthesis during a dual balance-cognition task in children and young adults with cochleovestibular loss* https://youtu.be/P5Gtlb_Qhhc

Auditory Plasticity and Training: Invited (I) and Featured (F) Recorded Talks

Yael Zaltz (I) *Auditory skill learning* https://youtu.be/KNKZvSRtAOY

Amanda M. Fullerton (F) *Stimulus-specific differences in cross-modal activity and functional connectivity in post-lingually deaf ci users using functional near infrared spectroscopy (FNIRS)* https://youtu.be/-NKlfDgFAXY

Outcomes and Predictive Factors: Invited (I) and Featured (F) Recorded Talks

Joerg M. Buchholz (I) *Effect of test realism on speech understanding in noise for bilateral cochlear implant users* https://youtu.be/fJyPOiz4xYU

Inga Holube (I) *Ecological momentary assessment: Opportunities and applications in hearing device evaluations* https://youtu.be/0Qec73CDpsk

Sarah E. Hughes (I) *From recipient experience to fundamental measurement: Developing a new patient-reported outcome measure of perceived listening effort* *https://youtu.be/ljlrXZrowPw*

Zilong Xie (F) *Effect of chronological age on pulse rate discrimination in adult cochlear-implant users* *https://youtu.be/Me4z6JrRK6U*

Wednesday Q&A sessions for Invited and Featured Recorded Talks and Posters

2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall

Topics: Neural Rhythms, Attention, Cognition and Effort, Auditory Plasticity and Training, Outcomes and Predictive Factors

Auditory attention and learning,

Thursday 15 July 2021

Device technology developments & central auditory prostheses

https://youtu.be/eZJPqRmAzSA

Live Session (S) chairs: Waldo Nogueira and Qian-Jie Fu

14.00 Hubert Lim (S) *Development and translation of a new auditory nerve implant*

14.30 Rob Shepherd (S) *Cochlear implants and the neurotechnology revolution*

15.00 Charley Della Santina (S) *Long-term outcomes of vestibular implant stimulation on eye stabilizing reflexes, posture, gait, dizziness, quality of life and hearing*

Device Technology: Invited (I) and Featured (F) Recorded Talks

Tobias Dombrowski (I) *Towards the optical cochlear implant: Optogenetic stimulation of the auditory pathway and the transfection of spiral ganglion neurons* *https://youtu.be/tLzoKIplgh4*

Mark Fletcher (I) *Using haptic stimulation to enhance auditory perception in cochlear implant users* *https://youtu.be/eAnrytymWUk*

Joshua G. W. Bernstein (F) *Headphones over the sound processor for remote clinical and research applications* *https://youtu.be/9Da3FL73I9c*

David Mark Landsberger (F) *Apical stimulation without longer electrode arrays* *https://youtu.be/My3dl3LJEjE*

Signal Processing: Invited (I) and Featured (F) Recorded Talks

Tobias Goehring (I) *Investigating causal mechanisms of speech perception with cochlear implants: Findings with spectral blurring* *https://youtu.be/pFiGpq3tIyE*

Leah Muller (F) *The cochlear implant Hackathon: Crowdsourced algorithm generation for improved auditory performance* *https://youtu.be/7xawp56KF4A*

Thursday Q&A sessions for Invited and Featured Recorded Talks and Posters

2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall

Topics: Device Technology, Signal Processing

https://youtu.be/DLuYoyeoRII

Friday 16 July 2021

Binaural/bilateral/bimodal hearing, devices and signal processing

Live Session (S) chairs: Matt Goupell and Karen Gordon and Liat Kishon-Rabin

7.00 Elisabeth Wallhäusser-Franke (S) *How does the brain cope with bimodal listening?*
7.30 Rene Gifford (S) *Emergence of binaural cue sensitivity in pediatric CI recipients with acoustic hearing preservation*
8.00 Stefan Zirn (S) *Interaural stimulation timing mismatch in bimodal listeners: Effect on sound source localization and spatial unmasking of speech*

8.30 Closing session (end of live talks, but recorded talks, posters and Q&A sessions continue until 18:00)

Bilateral, Binaural, Bimodal, EAS Stimulation: Invited (I) and Featured (F) Recorded Talks

Margaret T. Dillon (I) *Frequency-to-place mismatch in electric-acoustic stimulation device users: Effects on speech recognition and modified mapping procedures* *https://youtu.be/JMt5M13ZGyM*

Ellen Peng (I) *A deeper understanding of binaural sensitivity in children with bilateral cochlear implants revealed through eye gaze* *https://youtu.be/knO6v90fcys*

Andrew Curran (F) *Hemisphere-specific degradations in neural ITD processing following single-sided deafness (SSD) are associated with alterations in temporal rate coding* *https://youtu.be/09VcjulVwfY*

Kristina DeRoy Milvae (F) *Sound localization and spatial release from masking in bilateral cochlear implant listeners with linked automatic gain controls* *https://youtu.be/iBPR9GR9gxc*

Grace Hyerin Kim (F) *Providing anchors for measuring binaural fusion with cochlear implant users* *https://youtu.be/-lnsp2AKIcE*

Yang Zhang (F) *Bimodal interactions between acoustic and electric binaural stimulation in auditory cortex of awake marmosets with unilateral cochlear implant* *https://youtu.be/szY4ryQwpg4*

Music and Pitch: Invited (I) and Featured (F) Recorded Talks

Jeremy Marozeau (I) *Using atonal music to understand musical experience of ci users* https://youtu.be/rn3lldhkaZE

Simin Soleimanifar (F) *The voice quality in cochlear implant users* *https://youtu.be/uOXq9Y2XN84*

Rudolph C. Uys (F) *Cochlear implant users' perception of musical timbre dimension* *https://youtu.be/yVU27j5TrVM*

Friday Q&A sessions for Invited and Featured Recorded Talks and Posters

2:00-3:00 and 11:00-12:00 and 17:00-18:00 in the Poster Hall
Topics: Bilateral, Binaural, Bimodal, EAS Stimulation, Music and Pitch

INVITED SPEAKER ABSTRACTS

Machine Learning and AI – Invited Speaker Abstracts

Live Session Talk

1543: OPPORTUNITIES AND CHALLENGES FOR MACHINE LEARNING IN AUDITORY IMPLANTS

Waldo V Nogueira
Department of Otolaryngology, Hannover Medical School and Cluster of Excellence “Hearing4all”, Hanover, DEU

In general, cochlear implant users face severe limitations when they try to understand speech with another competing speaker, background noise or reverberation. Moreover, large individual differences and considerable unexplained variability exist in speech recognition outcomes for cochlear implant users. Machine learning can be used in the front-end stage or in the sound coding strategy of the cochlear implant sound processor to aid the listener in terms of speech understanding when using these devices. Moreover, machine learning can be applied to decode brain signals and inform these front-end and sound coding strategies to enhance the desired target sound and attenuate the others. In another domain, machine learning will likely improve audiological diagnostics of hearing loss to provide the best treatment and help us understanding the variability in speech intelligibility outcomes with cochlear implants.

This presentation will give an introduction to artificial intelligence, machine learning and deep learning. Potential applications of machine learning as a front-end processor, as a sound coding strategy or even as a method to decode brain signals will be outlined. Moreover, the talk will discuss potential applications of machine learning combined with big data to predict outcomes with these devices and to support auditory precision diagnostics. This includes the use of machine learning for the analysis of medical data such as computed tomography and electrophysiological signals and for the creation of novel computational models of hearing with auditory implants.

Finally, the talk will outline challenges for further progress in machine learning including the need for large sample sizes and data structures, bias, interpretability and hardware limitations.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC 2177/1 - Project ID 390895286.

Live Session Talk

1549: BRAIN-CONTROLLED ASSISTIVE HEARING TECHNOLOGIES: CHALLENGES AND OPPORTUNITIES

Nima Mesgarani
Columbia University in the City of New York, New York, NY, USA

Listening in noisy and crowded environments is exceptionally challenging for hearing-impaired listeners. Assistive hearing devices can suppress certain types of background noise, but they cannot help a user focus on a single conversation amongst many without knowing which speaker is the target. Our recent advances in scientific discoveries of speech processing in the human auditory cortex have motivated several new paths to enhance the efficacy of hearable technologies. These possibilities include speech neuroprosthesis which aims to establish a direct communication channel with the brain, auditory attention decoding where the similarity of a listener's brainwave to the sources in the acoustic scene is used to identify the target source, and increased speech perception using electrical brain stimulation. In parallel, the field of speech signal processing has recently seen tremendous progress due to the emergence of deep learning models, where even solving the multi-talker speech recognition is no longer out of reach. I will discuss the recent efforts in bringing together the latest progress in speech neurophysiology, brain-computer interfaces, and speech processing technologies to design and actualize the next generation of assistive hearing devices, with the potential to augment speech communication in realistic and challenging acoustic conditions.

Live Session Talk

1526: DETECTION OF AUDITORY ATTENDED OBJECT WITH CONGRUENT AUDIOVISUAL SPEECH

Jing Chen, Zhen Fu, Bo Wang
Peking University, Beijing, CHN

Hearing impaired (HI) listeners usually have troubles to attend to the intended talker in a complex auditory scene with multiple simultaneous talkers and background noises. Although advanced speech enhancement technologies could suppress background noise to a certain degree, they usually fail to selectively amplify the speech from the target speaker as they cannot identify the listener's auditory attended object (AAO) in multi-speaker environments. Recently, the auditory attention decoding (AAD) methods with EEG have been widely studied to detect the AAO, which could guide the design of speech enhancement algorithms integrating the detection of AAO.

Previous studies mainly focused on audio-only condition. However, in real face-to-face conversational scenes, audio with additional congruent visual input (such as lip-reading) is more common. It is suggested that the visual cues obtained by eye-gazing the target talker is beneficial to speech perception and would enhance the cortical tracking to continuous speech for both (Normal hearing) NH and HI listeners. However, the AAD in congruent audiovisual scenario was rarely studied and its performance remained unknow. Here, we investigated the EEG-based AAD on audiovisual speech with both NH and HI listeners. For NH group, the AAD accuracy can improve 14% with the benefit of visual input. For HI group, this improvement can achieve 21% averagely, although listeners' performance were diverse a lot. Individual differences among HI listeners were analyzed by comparing their behavioral performance on auditory temporal acuity, speech perception, and so on.

In daily conversation, listeners switch AAO between talkers, and they saccade and rotate head to direct the eye-gaze accordingly. To detect the switch of AAO and improve the efficiency of AAD, we aimed to combine EEG with horizontal electrooculography (HEOG) and neck electromyography. Firstly, a HEOG and NEMG based auditory attention switching detection (AASD) method was proposed. The results showed that, with optimized input type and classifier, the AASD algorithm had a lower delay (< 2 s) and missing alarm rate (about 3.1%). In addition, two AAD algorithms based on the convolutional recurrent neural network (CRNN) regression model and CRNN classification model were proposed. Results showed that for shorter decoding windows (2 s and 5 s), AAD accuracies of the two proposed models were both higher than the state-of-the-art model of the same type (the absolute improvement is about 5%). And the proposed models were shown with better interpretability and generalization. Furthermore, it was verified that the combining strategy between AAD and AASD methods was feasible, in which the calculation cost of AAD was significantly reduced to 30% while not affecting the accuracy.

Invited Recorded Talk

1541: COGNITIVE-DRIVEN BINAURAL BEAMFORMING FOR HEARING DEVICES USING EEG-BASED AUDITORY ATTENTION DECODING

Simon Doclo
Dept. Medical Physics and Acoustics and Cluster of Excellence Hearing4all,
University of Oldenburg, Oldenburg, DEU

During the last decades significant progress has been made in multi-microphone speech enhancement algorithms for hearing devices. Nevertheless, the performance of most algorithms depends on correctly identifying the target speaker to be enhanced. To identify the target speaker from single-trial EEG recordings in an acoustic scenario with two competing speakers, several auditory attention decoding (AAD) methods were recently proposed. Aiming at enhancing the target speaker and suppressing the interfering speaker and ambient noise, in this contribution we present a cognitive-driven speech enhancement system, consisting of a binaural beamformer which is steered based on AAD and estimated relative transfer function (RTF) vectors of both speakers [1,2]. For binaural beamforming and to generate reference signals for AAD, we consider either minimum-variance-distortionless-response (MVDR) beamformers or linearly-constrained-minimum-variance (LCMV) beamformers. Contrary to the binaural MVDR beamformer, the binaural LCMV beamformer allows to preserve the spatial impression of the acoustic scene and to control the suppression of the interfering speaker, which is important when intending to switch attention between speakers. For a reverberant acoustic scenario with two competing speakers and diffuse babble noise, 64-channel EEG responses with 18 participants were recorded. The speech enhancement performance of the proposed system was evaluated in terms of the binaural signal-to-interference-plus-noise ratio (SINR) improvement. Furthermore, we investigate the impact of RTF estimation errors and AAD errors on the speech enhancement performance. The experimental results show that the proposed system using LCMV beamformers yields a larger decoding performance and binaural SINR improvement (in the range of 4 to 7 dB) compared to using MVDR beamformers.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project ID 390895286 – EXC 2177/1.

[1] A. Aroudi, S. Doclo, Cognitive-driven binaural beamforming using EEG-based auditory attention decoding, IEEE/ACM Trans. Audio, Speech and Language Processing, vol. 28, pp. 862-875, 2020.

[2] A. Aroudi, M. Delcroix, T. Nakatani, K. Kinoshita, S. Araki, S. Doclo, Cognitive-driven convolutional beamforming using EEG-based auditory attention decoding, in Proc. IEEE International Workshop on Machine Learning for Signal Processing, Espoo, Finland, Sep. 2020.

Peripheral and Central Physiology, Auditory Modeling – Invited Speaker Abstracts

Live Session Talk

1531: UNDERSTANDING INTRACOCHLEAR ELECTROCOCHLEOGRAPHY WITH A COMPUTATIONAL MODEL

Margriet van Gendt, Kanthaiah Koka, Randy Kalkman, Christiaan Stronks, Jeroen Briaire, Johan Frijns
Leiden University Medical Centre, Leiden, NLD; Advanced Bionics, Valencia, CA, USA

Intracochlear electrocochleography (ECochG) is a potential tool for the assessment of residual hearing in cochlear implant users during implantation and of acoustical tuning post-operatively. It is, however, unclear how these intracochlear ECochG recordings depend on stimulus characteristics, morphology and hair cell degeneration. By combining a peripheral model of hair cell activation [1] with a 3D volume-conduction model of the current spread in the cochlea [2] a model was developed that can simulate intracochlear ECochG recordings [3]. The goal of the current study was to verify whether the model outcomes match real ECochG data and to aid in the interpretation of intra- and postoperative ECochG recordings by modeling ECochGs in cochleae with normal hair cells and with various patterns of hair cell degeneration. For this purpose, model predictions were compared to post-operative intracochlear ECochG recordings from CI-subjects.

The developed model replicated characteristics seen in intracochlear ECochG recordings in the temporal, spectral and spatial domain. 3D volume conduction simulations showed that the intracochlear ECochG is a local measure of activation. This local sensitivity was reflected in a steep falloff of impedances with distance along the basilar membrane. In line with the theory of place-coding and the level-dependency of hair cell activity, increasing stimulus level resulted in wider tuning. The peaks shifted basally with increasing stimulus frequency. The exact location of the peak CM amplitude on the array depended on the cochlear morphology and implant type. Double peaks were seen in response to the highest stimulus levels. These double peaks could be either attributed to cross-turn sensitivity or wide tuning of the hair cells. Inner hair cells showed a sharper tuning than outer hair cells. Onset responses and higher harmonics were dependent on the pattern of hair cell loss. Simulations showed that the phase responses can be reliably recorded when spatial sampling is high, but aliasing might occur with spatial under-sampling.

We conclude that the model reproduces recordings of intracochlear hair cell responses in CI-subjects. Different characteristics in the CM response turn out to be indicative of particular patterns of hair cell loss. Therefore, this model of intracochlear ECochG may be a valuable tool for understanding and diagnosing the etiology of hearing loss

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Live Session Talk

1545: AUDITORY-NERVE DEGENERATION IN HUMANS AND THE EFFECTS OF COCHLEAR IMPLANTATION

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Recent animal work has suggested that cochlear nerve fibers are more vulnerable than hair cells in many forms of acquired sensorineural hearing loss, and our histopathological analysis of autopsy specimens correspondingly shows that surviving inner hair cells lose more than half their neuronal connections by age 60 yrs in normal-aging humans. This subtotal primary neural degeneration does not alter audiometric thresholds, but contributes significantly to difficulty with speech discrimination, even in quiet, and is exacerbated throughout the cochlea in cases with a noise-exposure history. Examination of temporal bones from unilateral cochlear implant cases, suggests that the implantation does not accelerate the rate of neural loss, but may lead to apical hair cell loss, even in cases with hybrid devices.

Live Session Talk

1525: WHAT PHYSIOLOGICAL DIFFERENCES UNDERLIE VARIATION IN SPEECH PERCEPTION BENEFIT FOR CI USERS?

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Understanding the variation among CI recipients in benefit gained from a CI is one of the most persistent challenges faced in our research field. Only by understanding the source of a limitation in an individual can a strategy be developed to improve or optimise their outcome. In this talk I will summarise what we know about the effects of peripheral cochlear pathology, central auditory processing difficulty, and cortical language network changes on speech perception ability. In the periphery, variation in neural survival along the cochlea will lead to neural “dead regions” in which cross-frequency listening will distort the perceived spectrum of speech sounds. In the central auditory system, difficulty perceiving relative changes in intensity across electrode positions will make speech understanding difficult. At the cortical level, plastic changes in the multimodal language networks due to deafness will affect the ability to understand speech. At the Bionics Institute, we have developed three diagnostic tests that will quantify in individual CI users the three levels of speech-sound processing described above. In a longitudinal study, we are applying the diagnostic tests immediately after switch-on and following speech perception ability over the first 12 months of CI use to confirm the predictive value of the tests. The long-term goal is to use the diagnostic tests to guide optimisations of implant parameters at start-up to improve speech perception benefits for each individual.

The study is funded by the National Health and Medical Research Council of Australia (GNT1163894). Robert Luke was supported by an Australian Research Council Laureate Fellowship (FL160100108). The Bionics Institute acknowledges the support it receives from the Victorian Government through its Operational Infrastructure Support Program.

Invited Recorded Talk

1537: NEURAL TRACKING OF THE SPEECH ENVELOPE IN COCHLEAR IMPLANT USERS

Ben Somers, Eline Verschueren, Tom Francart
KU Leuven – University of Leuven, Department of Neurosciences, ExpORL, Leuven, BEL

Electrophysiological measures in response to auditory stimuli have great potential for objectively assessing auditory functioning in cochlear implant users and fitting implant settings accordingly. However, current clinical applications are limited to using short, transient stimuli which target the periphery of the auditory system, such as the auditory nerve (ECAPs) or responses from the brainstem (EABRs). Responses to continuous stimulation at clinical rates, for instance, modulated tones (EASSRs) reflect frequency-specific higher-level processing in the auditory pathway. However, none of these techniques make use of ecologically valid stimuli such as natural running speech.

The temporal envelope of a speech signal, one of the most important cues for speech intelligibility, is tracked by the listener’s brain. Studies with normal hearing participants have shown that this neural representation of the envelope can be decoded from electroencephalograpic (EEG) recordings, and that the outcome of this decoding analysis relates to speech intelligibility. This forms the basis for a newly developed objective measure of speech intelligibility which can also be applied to cochlear implant users. Furthermore, this method enables assessment of speech envelope encoding in the auditory pathway, which is appealing to apply to cochlear implant users as current stimulation strategies mainly rely on encoding envelope information.

The major challenge in applying EEG-based neural envelope tracking methods in cochlear implant users is the presence of electrical stimulation artifacts originating from the cochlear implant itself. When presenting a speech stimulus at clinical rates, these artifacts are temporally overlapping. Furthermore, the stimulus artifacts contain the same modulated envelopes as the stimulus and are thus highly correlated with the targeted neural responses, making their interpretation challenging due to false positives.

In this contribution, we will present an overview of our work to translate neural envelope tracking methods to cochlear implant users. Using new techniques to reduce or avoid the effects of electrical stimulation artifacts, we demonstrated that envelope tracking can be measured in cochlear implant users, and that the obtained measures reflect the intelligibility of the speech stimulus. Efficacy of artifact removal is evaluated in multiple ways, for instance making use of subthreshold stimulation. Furthermore, interpretations of the envelope tracking models reveal interesting information about the temporal and spatial dynamics of how the electrically stimulated brain responds to speech.

This project has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation program (No. 637424, ERC Starting Grant to Tom Francart) and ERC Proof of Concept grant OSIRIS (No. 893462), from Research Foundation Flan-ders (FWO) PhD grants for Strategic Basic research to Ben Somers and Eline Verschueren (No. 1S46117N and 1S86118N), and from KU Leuven special research fund C3/20/045.

Invited Recorded Talk

1535: CORTICAL OSCILLATIONS REVEAL LOSS OF TOP-DOWN INTERACTIONS FOLLOWING CONGENITAL DEAFNESS

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Congenital deafness affects the functional and anatomical properties of the auditory system (Kral et al., 2019, Ann Rev Neurosci). It has been suggested that congenital deafness affects predominantly corticocortical functional connections within but also beyond the auditory system (the connectome model of deafness, Kral et al., 2016, Lancet Neurol). This may lead to increased risk of cognitive deficits in deaf children. Indeed, so-called induced responses, indicative of corticocortical interactions, were reduced in the auditory cortex of congenitally deaf cats (Yusuf et al., 2017, Brain). In the present study we directly investigated effective connectivity between primary and secondary areas of congenitally deaf cats (CDC).
In adult hearing cats (HC) and CDCs, responses to acoustic and electric stimulation (through a cochlear implant) were compared. Recordings were in the primary auditory field (A1) and the higher order posterior auditory field (PAF) using multielectrode arrays. Penetrations were histologically reconstructed. For effective connectivity pairwise phase consistency, weighted phase-lag index and nonparametric Granger causality were determined and compared.
CDCs demonstrated a substantially reduced stimulus-related corticocortical coupling in the connectivity measures used. Largest deficits were observed in sensory-related top-down interactions, in the alpha and beta band. The data document that corticocortical interactions are dependent on developmental hearing experience. In absence of hearing the effective connectivity reorganizes. This suggests that the congenitally deaf brain cannot incorporate top-down prediction information into auditory processing and thus have a deficient mechanism of predictive coding.

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Invited Recorded Talk

1542: VOLTAGE-GATED ION CHANNELS TUNE THE KINETICS AND SENSITIVITY OF SPIRAL GANGLION NEURONS

Robin L. Davis
Rutgers University, Piscataway, NJ, USA

The simple bipolar morphology of type I spiral ganglion neurons belies the underlying complexity of their morphological and electrophysiological phenotypes. Studies have shown, as with aspects of soma size and axon diameter, that action potential kinetics and neuron sensitivity vary both tonotopically and locally throughout the spiral ganglion. The myriad identified voltage-gated ion channels that contribute to the signature heterogeneous electrophysiological profile in the spiral ganglion are commensurately distributed as are their neurotrophin regulators. Moreover, the fine structure of action potentials generated experimentally with constant current pulses at the somata of type I neurons has also been observed in invading action potentials generated at nodes of Ranvier in the myelinated distal axon segment. This indicates that the highly-tuned analog components of action potentials are likely preserved as they propagate along myelinated axons to their central targets. Thus, the many classes of voltage-gated ion channels and their complex organization contributes to shaping the responses of spiral ganglion neurons. This process undoubtedly works in tandem with the prolific efferent innervation at the postsynaptic membrane, indicating that neurons receiving identical input are capable of generating distinctly different output. The resulting encoding strategy of dynamic heterogeneity, in which intrinsically-diverse electrophysiological properties of spiral ganglion neurons are actively regulated, results in the almost unlimited potential to shape neural signals as they are transmitted to higher auditory processing centers.

Invited Recorded Talk

1548: 3D CURRENT SPREAD AND NEURAL MODELLING OF HUMAN COCHLEAE

Tania Hanekom
Bioengineering, University of Pretoria, Pretoria, ZAF

Accurate computational models of the electrically stimulated auditory system are crucial for unravelling the many intertwined factors that affect hearing performance with cochlear implants (CIs). It is mostly not possible to test the physiological effect of a single parameter in a CI user because the required procedure would be highly invasive, or the parameters form part of the same effect and can therefore not be separated in an experimental setup. In contrast, the majority of parameters are accessible and separable in a computational model. Computational models may consequently create a versatile and powerful platform to (i) investigate, analyse and test hypotheses about hearing phenomena on an individual user basis, and (ii) inform objective programming of the device and application of other interventions in the management and care of CI users.

At the core of computational models of the auditory periphery is the prediction of the 3D spread of stimulation current throughout the cochlear volume. It is known that current spread is affected by the anatomical and morphometric characteristics of an individual cochlea, i.e. 3D current spread is unique for each cochlea. There is still much work to be done on improving the accuracy of the mathematical representation of the detailed anatomy of living CI users' cochleae as the resolution of the source data is severely limited. Without an accurate representation of the various conductivity domains that constitute the volume conductor, the subtle differences that distinguish one CI user from another may be lost in the modelling domain and therefore limit the application of such models in clinical application. The first part of the presentation will review work in our group that focuses on computational reconstruction of the detailed anatomy of the cochlea from a subset of landmarks that are readily measured on low-resolution clinical images of a CI user's cochlea.

Once the current spread has been calculated, a variety of neural models exist to estimate the response to a particular stimulation. Physiologically-based neural models are preferred to translate predicted current spread to neural firing patterns as the interface between the two types of models is founded in the biophysical behaviour of the system. Two primary factors need to be accounted for in a model of the auditory nerve that is aimed at predicting user-specific responses. Firstly, the model should be able to predict the spatial and temporal response to electrical stimulation in general, and secondly, user-specific variations in neural health along the cochlea should be included. Both these requirements have been addressed with some success in numerous studies, but as for the anatomical models, neural models can also not capture all the subtleties of a specific user's response to intracochlear stimulation yet. The second part of the presentation will highlight work that has been done to include person-specificity in the neural models.

The overarching objective of our work on computational models is to support the development of tools that may be of use in person-centred care of CI users. It is envisioned that computational models will eventually be developed to a level where their clinical application becomes standard practice within the management and care of CI users. The presentation will conclude with a brief look at the application of the models in the management of CI users.

Neural Rhythms, Evoked Potenitals, and Imaging – Invited Speaker Abstracts

Live Session Talk

1550: FROM VIBRATIONS IN THE EAR TO ABSTRACTIONS IN THE HEAD

David Poeppel
Ernst Struengmann Institute for Neuroscience, Frankfurt, DEU

The brain has rhythms - and so do music and speech. Recent research reveals that the temporal structure of speech and music and the temporal organization of various brain structures align in systematic ways. The role that brain rhythms play in perception and cognition is vigorously debated and continues to be elucidated through neurophysiological studies of various types. I describe several intuitively simple but surprising results that illuminate the temporal structure of perceptual experience. From recognizing speech to building abstract mental structures, how the brain constructs and represents time reveals unexpected puzzles in the context of speech perception and language comprehension.

Live Session Talk

1534: RATE AND ENVELOPE ENCODING IN THE ELECTRICALLY-STIMULATED AUDITORY PATHWAY

Robin Gransier
KU Leuven, ExpORL, Leuven, BEL

Speech contains many temporal modulations that occur at different timescales, for example temporal envelope modulations and the fundamental frequency. All these temporal modulations are important for speech perception. Cochlear implant (CI) users make predominately use of the temporal envelope to perceive speech, which consists of many low-frequency modulations. Although envelope modulations provide CI users with enough information to perceive speech - based on a limited number of spectral channels – in quiet, CI users struggle when listening to speech in challenging listening conditions. Furthermore, the ability to listen to speech in challenging listening conditions is highly variable across CI users. The neural encoding of speech modulations has been postulated to be an important factor to account for this variability. Several factors, such as the electrode-neuron interface, the response of the auditory pathway to electrical stimulation, and the effect of long-term deafness have been shown to affect the encoding abilities of the auditory pathway. Given that differences in neural encoding could potentially account for the differences in outcome across CI recipients makes that insight in these processes can be valuable for the optimization and development of fitting and stimulation strategies.

Non-invasive electrophysiological measures can provide valuable insights in these aspects. Measures that probe the phase-locking ability of the different neural structures of the electrically-stimulated auditory pathway are of particular interest, as they can potentially be used to directly link the ability of the auditory pathway to encode the CI stimulation sequence to the outcome with a CI. For example, how the ability to encode rate is related to pitch perception and speaker identification or how the neural encoding of envelope modulations is associated with speech perception in noise. We will present our recent research, in which we used different electrophysiological measures to assess rate and envelope modulation encoding in CI users. Furthermore, we will discuss the link between these measures and speech perception, and their potential for the evaluation of fitting strategies and the development of new neuro-inspired stimulation strategies.

Live Session Talk

1547: RELATING SOUND-EVOKED BRAIN RESPONSES TO ASPECTS OF SPEECH UNDERSTANDING FOR COCHLEAR IMPLANT USERS

Deborah Vickers, Ben Williges, Lindsey Van Yper, Wiebke Lamping, Marina Salorio-Corbetto, Manohar Bance, David McAlpine, Jaime Undurraga
University of Cambridge, Cambridge, GBR; Macquarie University, Sydney, AUS

Aim: The quality of the transmission of speech information in cochlear implant (CI) users is reliant upon the ability to detect, track, discriminate and process the amplitude-modulated (AM) envelope of speech sounds independently in different channels. Information transmission through the electrically stimulated auditory pathway can be hindered at many stages due to, for example, spread of electrical current, survival of inner-ear neurons and the neural representation of dynamic spectro-temporal cues. In this research we objectively measured the cortical representation of AM stimuli to understand the neural processing of dynamically changing modulation rates, within the speech cue range.

Methods: Using the alternating auditory change complex (ACC) paradigm (Vickers et al. 2019, Undurraga et al. 2020) we measured the representation of AM stimuli varying at rates typically present in human speech. We used a slow (0.5Hz) alternating rate between different AM frequencies, to evoke a transient cortical ACC, and a faster alternating rate, designed to trigger neural adaptation at a higher (6-7Hz) alternating rate to elicit the auditory change following response (AC-FR). We tested adult normal hearing listeners (aged 18-70) with insert earphones (ER-3). For adult CI users (aged 62-80) we used direct stimulation using the Nucleus Implant Controller-3 research interface.Electroencephalogy (EEG) was conducted with 64-channel high resolution BioSemi ActiveTwo system at a sampling rate of 16 384 Hz using channels arranged in 10–20 configuration. Artefact was removed using a modified Denoising Separation Approach and Interpolation techniques and significance of responses were assessed using the Hotelling T-squared test (Undurraga et al. 2021).

Results: We demonstrated that CI listeners, like normal-hearing listeners-are sensitive to transitions in the AM rate due to clear N1-P2 responses being elicited in response to modulation rate changes. However, CI listeners showed poorer AC-FRs at the higher alternation rate which we believe was due to greater cortical adaptation to alternating cues at speech-like rates. For all of the responses age effects were not observed.

Conclusion: The alternating ACC responses to different AM rates are clear for both normal hearing and CI listeners. The AC-FR suggested cortical adaptation at higher alternation rates, within the syllabic range, which potentially indicates that important changes in the speech signal might be missed by CI listeners. When measured on a channel-by-channel basis this objective measures paradigm could also be used to identify poor CI channels to inform re-mapping paradigms.

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. **Invited Recorded Talk**

1551: SYNCHROTRON IMAGING OF THE INNER EAR

Sumit Kishore Agrawal
Western University, London, CAN

Since synchrotron radiation phase-contrast imaging (SR-PCI) was first performed on intact, unstained human cochleae, a tremendous amount of anatomic knowledge has been extracted from the detailed images. In particular, visualization of the basilar membrane, spiral ganglion, and peripheral axons in three dimensions has allowed the creation of detailed tonotopic maps of the cochlea. This talk will summarize the first patient-specific tonotopic mapping formula developed using these images. Finally, future applications using artificial intelligence analysis will also be discussed.

Auditory Attention/Learning/Training/Outcomes – Invited Speaker Abstracts

Live Session Talk

1544: EFFECTS OF DISTRACTION ON PROCESSING AND STORING SOUND STREAMS

Barbara Shinn-Cunningham, Wusheng Liang, Christopher A Brown
Carnegie Mellon University, Pittsburgh, PA, USA; University of Pittsburgh, Pittsburgh, PA, USA

Listening in the real world means coping with unexpected interruptions, like the loud POP of a champagne bottle as you listen to a congratulatory speech. It is well known that unexpected disruptions involuntarily grab attention, interfering with perception of whatever you are trying to focus on. This talk reviews evidence that separate brain networks are responsible for controlling volitional "top down" attention and for supporting the automatic "grab of attention" driven by surprising events. In addition, behavioral evidence will be presented showing that the effects of "bottom up" interruptions go beyond interfering with perception-- they also interfere with storing information about ongoing auditory streams in working memory. Finally, we will consider how degraded sensory representations, such as experienced by cochlear implant listeners, may affect processing of unexpected interruptions.

Live Session Talk

1540: NEURAL CORRELATES OF MULTI-TALKER LISTENING IN COCHLEAR IMPLANT USERS

Brandon T. Paul
Ryerson University, Toronto, CAN

Cochlear implant (CI) users often report difficulty when listening to speech in the presence of competing talkers in the background. These multi-talker listening difficulties could arise due to deficits in auditory object formation, where a listener has difficulty binding overlapping speech features into distinct percepts, or difficulties with selective attention, where one of many competing objects is chosen for further cognitive processing. Two neural signatures of multitalker listening measured by EEG that may partially capture or reflect auditory object formation and attentional selection are 1) enhanced “neural tracking” to attended speech compared to ignored speech, and 2) increases in alpha band (8-12 Hz) power ipsilateral to the spatial location of the attended talker, which may suppress cortical processing of an ignored talker.

This talk will present data collected across multiple studies to address three questions: How can we record these signals in CI users using EEG, can they tell us about object formation and selective attention, and finally, do they relate to clinically measured speech outcomes and subjective quality of life?

Live Session Talk

1522: INDEXING THE ACOUSTIC AND LINGUISTIC PROCESSING OF NATURAL SPEECH USING LOW- AND HIGH-FREQUENCY EEG

Shyanthony R. Synigal, Emily S. Teoh, Edmund C. Lalor
University of Rochester, Rochester, NY, USA
Trinity College Dublin, University of Dublin, Dublin, IRL

The human auditory system tracks the slow-varying temporal dynamics of speech (or the speech envelope) in both single speaker and multi-speaker situations. Electrocorticography (ECoG) studies have shown that speech envelope processing is strongly reflected in high gamma power (around 70-150 Hz) neural activity. In contrast, non-invasive electro-/magnetoencephalography (EEG/MEG) techniques have shown that neural activity below 16 Hz tracks speech dynamics; high gamma activity is not typically included as those signals are smeared and filtered by dura mater and the skull. Despite its reputation for having a poor signal to noise ratio, we investigated if high gamma power scalp recorded EEG carries useful stimulus-related information and assessed if that information was complementary to low frequency EEG indices of speech processing. Specifically, we used linear regression techniques to investigate speech envelope tracking and attention decoding in low frequency EEG, high gamma power EEG, and in both EEG signals combined. As well as discussing the results of this investigation, we will also discuss how the cortical tracking of the speech envelope and other higher-level speech features relate to the intelligibility of both clean and degraded speech. Lastly, we will discuss how the abovementioned work may help to better understand how speech is encoded in the brain and how these tools may be useful in assessing cochlear implant performance.

This work was supported by an Irish Research Council Government of Ireland Postgraduate Scholarship (GOIPG/2015/3378) and by the Del Monte Institute for Neuroscience.

Invited Recorded Talk

1523: AUDITORY SKILL LEARNING

Yael Zaltz
Department of Communication Disorders, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, ,ISR

Much effort has been devoted in the past years to improving auditory perception for hearing impaired individuals who use cochlear implants (CI). Technological means that are aimed to enhance the resolution of the signal at the periphery level resulted in a significant but limited benefit, supporting the notion that top-down cognitive mechanisms need to be actively involved to compensate for the degraded input provided by the CI. One way to invoke efficient high-level cognitive and auditory processing of the incoming signal is via auditory training that can direct the auditory system to attend to the relevant acoustic properties of the stimuli. However, the characteristics of the learning process that may follow such training and the magnitude of the training-induced improvements in auditory perception are still largely unknown, even for listeners with normal hearing (NH). In the current lecture I will review recent studies from our lab that aimed to characterize auditory skill learning in NH listeners and to explore its dependency on training-related factors, including the length of training, the testing and the training method, and subject-related factors, including cognitive abilities and age. Specifically, I will describe how and when these factors may affect the time course of learning, the consolidation, retention and generalization of the learning gains, using a basic psychoacoustic task of frequency discrimination for training. I will also present a model that predicts the efficiency of auditory skill learning in school-age children, depending on the maturity of their bottom-up auditory processing and top-down cognitive abilities. Following the lecture, listeners will better understand the potential and constrains of auditory learning and will gain an important insight on brain plasticity at childhood and adulthood. The findings will show that the characteristics of auditory learning resemble those shown in the visual and motor modalities, and will support the notion of common underlying mechanisms for basic skill learning across different modalities. They will further suggest that the effect of the training protocol and the conditions of training may largely depend on the learner's top down and bottom-up processing capabilities. This information may help to set realistic expectations regarding the outcomes of auditory training in pathological populations, including CI users, and will support the view that training may best be tailored for each patient individually, depending on his or her cognitive and auditory abilities.

Invited Recorded Talk

1524: EFFECT OF TEST REALISM ON SPEECH UNDERSTANDING IN NOISE FOR BILATERAL COCHLEAR IMPLANT USERS

Joerg Matthias Buchholz, Javier Badajoz-Davila
Macquarie University, Sydney, AUS

The real-world experience of cochlear implant (CI) users' ability to understand speech in noisy environments often does not correlate well with the outcomes of laboratory assessments. This may be due to the rather artificial speech and noise stimuli used, which do not well reflect the complex acoustic properties of real-world environments. To understand the effect of test realism on individual sentence recall outcomes, 15 bilateral CI users were tested in three different conditions: (1) standard BKB sentences in babble noise, (2) standard BKB sentences in recorded realistic environments reproduced by a 3D loudspeaker array, and (3) realistic sentences taken from natural conversations and presented in the same realistic environments. Two environments were considered with signal-to-noise ratios of -2.2 and 1.4 dB, respectively. Performance decreased with increasing stimulus realism and varied significantly across participants. Average scores were 78% and 92% in the least realistic environments and decreased to 37% and 70% in the most realistic environments. The effect of the realistic noises was well predicted by the U50 derived from the output of the CIs' directional microphones. This was not the case for the realistic speech material, for which the modulation spectrum and overall clarity may be of additional relevance.

Invited Recorded Talk

1519: ECOLOGICAL MOMENTARY ASSESSMENT: OPPORTUNITIES AND APPLICATIONS IN HEARING DEVICE EVALUATIONS

Inga Holube, Petra von Gablenz, Joerg Bitzer
Institute of Hearing Technology and Audiology, Jade University of Applied Sciences, Oldenburg, DEU

Evaluations of hearing devices are commonly undertaken with speech tests and questionnaires under controlled conditions. For speech tests, words or sentences are typically presented in quiet or in (mostly stationary) noise coming from one or two loudspeaker directions. Questionnaires in use focus on the experiences in predefined listening conditions made in a past time period, e.g., the last four weeks, and the results are potentially biased by memory effects. Both methods, speech tests and questionnaires, suffer from limitations regarding their ecological validity and rarely consider the individual's specific demands in everyday life listening conditions. Hence, evidence of individual benefit is sometimes missing. An alternative approach called ecological momentary assessment (EMA) is rapidly gaining widespread use. It employs repeated assessments of individual everyday situations. Smartphones facilitate the implementation of questionnaires and rating schemes to be administered in the real life of study participants or patients during or shortly after the experience. In addition, objective acoustical parameters extracted from head- or body-worn microphones and/or settings from the device's signal processing unit can be stored alongside the questionnaire data. The advantages of using EMA include participant-specific context-sensitive information on activities, hearing-related experiences, and preferences. The collected data allow for describing the "auditory reality" of participants and opens up new insights into individual everyday hearing abilities. The method offers opportunities to complement results collected under controlled conditions and to enhance patient-centered health care. Challenges are among others compliance, usability of the EMA equipment, and the analysis of diverse individual data. This presentation will review the methodology and give examples for applications in hearing device evaluations.

Invited Recorded Talk

1529: FROM RECIPIENT EXPERIENCE TO FUNDAMENTAL MEASUREMENT: DEVELOPING A NEW PATIENT-REPORTED OUTCOME MEASURE OF PERCEIVED LISTENING EFFORT

Sarah E Hughes, Alan Watkins, Isabelle Boisvert, Frances Rapport, Catherine M McMahon, Hayley A Hutchings

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Background/Aims: The complexity of listening effort and its underlying mechanisms is well-established and the challenges this complexity presents for measurement are similarly well-recognised. This presentation describes the development and validation of the Listening Effort Questionnaire-Cochlear Implant (LEQ-CI), a new patient-reported outcome measure (PROM) of perceived listening effort for use with adult cochlear implant recipients. This research illustrates how the application of modern psychometric methods can: 1) provide theoretical insights into listening effort and 2) produce self-report instruments that satisfy the requirements for fundamental measurement (additive, conjoint measurement leading to interval scales).

Methods: Development and validation of the LEQ-CI proceeded according to international, consensus-based guidance and involved multiple stages: 1) a qualitative study with adult cochlear implant recipients to construct a conceptual framework for measurement; 2) an iterative process of instrument construction and refinement; and 3) initial psychometric evaluation within a Rasch measurement framework.

Outcomes: Grounded theory methods were applied to focus group (n = 17) and postal survey (n = 108) data to yield a conceptual framework for measurement that included three qualitative domains of listening effort and motivation. Instrument construction and iterative refinements produced a 21-item version of the LEQ-CI that underwent psychometric evaluation in a multi-centre field test (n = 330). The LEQ-CI was found to satisfy the Rasch model requirements for fundamental measurement, enabling the construction of an interval scale of perceived listening effort through Rasch transformation of the ordinal raw scores. Dimensionality analyses suggested motivational concepts (social connectedness, pleasure, effort-reward balance) to be components of perceived listening effort in daily life, consistent with the theoretical Framework for Understanding Effortful Listening (FUEL).

Conclusions: The LEQ-CI is the first PROM to be developed specifically for the measurement of perceived listening effort in daily life. It has potential for use both in research and clinical settings. The process of PROM development enabled a richer understanding of effortful listening in cochlear implantation whilst the use of Rasch analysis rendered the LEQ-CI suitable for co-calibration with performance outcome measures purported to index listening effort. Further validation of the LEQ-CI is planned.

Device Technology – Invited Speaker Abstracts

Live Session Talk

1536: DEVELOPMENT AND TRANSLATION OF A NEW AUDITORY NERVE IMPLANT

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Cochlear implants are considered one of the most successful neural prosthetics and have been treating patients with hearing loss for more than 40 years. They have been successful in restoring speech perception, especially in quiet environments; however, there remain limitations in nosier backgrounds and for appreciating more complex inputs, such as music and multiple talkers. One key limitation for cochlear implants towards achieving better hearing capabilities has been attributed to the electrode-neural interface. The cochlear implant electrode array is implanted into the cochlea and electrical current must transmit from the electrodes through the bony wall to reach the target auditory nerves, which results in spread of current and diffuse neural activation. With recent advances in neural technologies and neurotological surgical approaches, there are greater opportunities for pursuing an intracranial auditory prosthesis that targets the auditory nerve between the cochlea and the brainstem (auditory nerve implant, ANI). The ANI can be directly implanted into the auditory nerve with the aim to achieve more focused activation and greater transmission of auditory information to the brain compared to the cochlear implant. Initially, the ANI can be implanted in deaf patients who cannot be successfully implanted or sufficiently benefit from a cochlear implant due to anatomical distortions/obstruction of the cochlea or facial side effects. A 6-year NIH BRAIN Initiative grant has been awarded across five institutions and two medical device companies (MED-EL and Blackrock Microsystems) to develop and translate a new ANI through pre-clinical studies (Years 1-4), and then implant the ANI in three deaf patients through a pilot clinical trial (Years 5-6). Our team's approach for intraneural stimulation is to integrate well established neural technologies already being used in human patients for other clinical applications and neural targets. This integration includes the Utah Slanted Electrode Array (USEA; Blackrock Microsystems), which is merged together with the MED-EL SYNCHRONY2 cochlear stimulator. We are currently in the first 4-year pre-clinical phase. Success with our pre-clinical tasks will justify transition of the project into the 2-year clinical trial phase. The pre-clinical phase is focused on developing device integration approaches, device testing protocols, implant hearing simulations, surgical approaches, and regulatory strategy. We have developed and refined approaches to integrate the devices and are poised to have the first fully functional bench testing prototypes integrated this year. The integration approach utilizes a custom-designed interposer that preserves as much of the existing tooling, materials, and workflows of partner companies as possible. Furthermore, we have successfully developed cat and non-human primate models for pre-clinical testing for long-term device safety and functional evaluation. On the clinical side, our team has developed multiple surgical approaches to access the auditory nerve in the internal auditory canal. These include a newly developed infralabyrinthine-infracochlear hybrid approach that can potentially preserve vestibular function, and an approach where the inferior aspect of the auditory canal is exposed through a more traditional translabyrinthine procedure. In parallel, perceptual testing protocols and novel stimulation algorithms relevant for the ANI patients are being developed through simulations in normal hearing subjects and further evaluated in CI patients to permit comparison with hearing performance later observed in the actual ANI patients. The success of this project will not only open up new directions for auditory prosthetics, but will also provide improved neural technologies for other clinical applications relevant to the neural engineering community.

Funding: NIH BRAIN Initiative UG3 NS107688, MED-EL, Blackrock Microsystems.

Live Session Talk

1520: COCHLEAR IMPLANTS AND THE NEUROTECHNOLOGY REVOLUTION

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Neural prostheses electrically stimulate and/or record from excitable tissue to improve health outcomes. Devices such as heart pacemakers, deep-brain stimulators, spinal cord stimulators and cochlear implants (CIs) have improved the quality of life of millions of people over the past 50 years. The long-term safety and efficacy of these devices, in particular CIs, has generated a revolution in neurotechnology over the past 10 years leading to the development of a new generation of devices such as brain-machine interfaces for the control of robotic limbs; vestibular prostheses to correct balance disorders and bioelectronic medicine for the treatment of inflammatory diseases. The development of these technologies depends on multidiscipline collaboration across the sciences, engineering and clinical research.

With approximately 600,000 patients implanted, the CI is the most successful neural prosthesis developed to date. Their success is due to multiple factors including: (i) the anatomy & physiology of the auditory system is well understood; (ii) reliable techniques exist to measure hearing loss in adults and children; (iii) the cochlea is a tonotopically organized, mechanically stable structure providing a safe location for the insertion of an electrode array without damaging auditory neurons; (iv) the technology is sophisticated and tiny - the one device can be used in adults and children, while techniques such as reverse telemetry provide the opportunity to interrogate the device (e.g. electrode impedance) and the neural interface (evoked potentials); (v) a well-trained clinical team – modern Otology training ensures that CI surgery is not a major surgical challenge while Audiologist provide a key role in device fitting and (re)habilitation; (vi) CIs stimulate the auditory periphery, taking advantage of neural processing within the central auditory pathway to maximise the advantage of the plastic brain. This mature field is supported by an active research and commercial community that maintain close links with the clinical team to ensure that CIs will continue to evolve.

The confidence and knowledge generated by the long-term clinical success of implantable devices such as CIs, have resulted in a major expansion in the development, clinical trial and commercialisation of the next generation of neurotechnologies. However, there are still valuable lessons that have been learnt from CIs that can help accelerate the development of the next generation of neurotechnologies. Although the electrode-neural interface and the biomaterials used in these new devices may differ from early neural prostheses, these new initiatives will require significant multidisciplinary clinical, scientific and engineering expertise that can work with entrepreneurs that bring IP management, regulatory and clinical trials know-how, as well as commercialisation and manufacturing expertise.

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Live Session Talk

1532: LONG-TERM OUTCOMES OF VESTIBULAR IMPLANT STIMULATION ON EYE-STABILIZING REFLEXES, POSTURE, GAIT, DIZZINESS, QUALITY OF LIFE AND HEARING

Margaret R Chow, Desi P Schoo, Andrianna I Ayiotis, Peter J Boutros, Mehdi Rahman, Nicolas S Valentin, Stephen Bowditch, Yoav Gimmon, Kelly Lane, Brian J Morris, Celia Fernandez Brillet, Gene Y Fridman, John P Carey, Charles C Della Santina

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BACKGROUND: Bilateral vestibular hypofunction due to inner ear dysfunction causes chronic dizziness, postural instability, unsteady gait and decreased quality of life. Since 2016, we have been conducting a prospective first-in-human cohort study of vestibular implantation and 24 hour/day artificial semicircular canal stimulation to quantify effects on vestibulo-ocular reflex performance, posture, gait, disability, quality of life and hearing in patients disabled by this disorder.

METHODS: Nine participants with chronic bilateral aminoglycoside toxicity (n=7) or idiopathic hypofunction (n=2) underwent unilateral implantation 2-23 years after symptom onset (ClinicalTrials.gov NCT0272546). Preoperatively and at 6 months and 1 year post-implantation, we quantified vestibulo-ocular reflex performance using whole-body and head-on-body rotations; posture using the Bruininks-Oseretsky Test balance subtest and Modified Romberg with Eyes Closed on Foam; gait using the Dynamic Gait Index, Timed Up and Go and gait speed; patient-reported dizziness, disability and quality of life; and hearing. To quantify placebo effects, we performed posture and gait tests with the system stimulation in the treatment mode used at home (encoding head movement) and a placebo mode (stimulation at constant pulse rate and amplitude).

RESULTS: For every implanted semicircular canal in every participant, at least one electrode elicits vestibulo-ocular reflex responses that approximately align with the 3-dimensional axis of the implanted canal. Six months and 1 year post-implantation, median within-participant improvement from baseline equaled or exceeded minimally important differences for the Bruininks-Oseretsky Test, Dynamic Gait Index, gait speed, and all patient-reported outcome instruments. Five of nine implanted ears retained useful hearing; four did not. No serious unanticipated adverse events occurred. All participants have used their devices 24 hr/day or during all daytime hours since device activation.

CONCLUSIONS: Vestibular implant stimulation of semicircular canals reliably excites vestibular afferents during long-term use, drives directionally appropriate eye movement reflexes, and improves postural stability, gait, and self-reported dizziness, disability and quality of life in individuals with bilateral vestibular hypofunction.

Supported by NIDCD, Labyrinth Devices LLC and MED-EL GmbH.

Invited Recorded Talk

1472: TOWARDS THE OPTICAL COCHLEAR IMPLANT: OPTOGENETIC STIMULATION OF THE AUDITORY PATHWAY AND THE TRANSFECTION OF SPIRAL GANGLION NEURONS

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The Göttingen Cochlear Optogenetics Program aims to encounter the limitation of cochlear implants by replacing electrical stimulation with spatially confined optical stimulation of SGNs based on an optogenetics approach. Referring to this, recent work followed a broad range of related research from the transfection of SGNs to the technical development of optical cochlear implants (oCI).

We have successfully established the optogenetic stimulation of the auditory pathway in rodents following virus-mediated transfection of SGNs with channelrhodopsins. Fast opsins enabled SGN firing at near physiological rates and activated several stages of the auditory pathway. The spectral selectivity of the tonotopic activation as well as the stability and characteristics of microfabricated LED cochlear implants was demonstrated. Behavioral studies in rodents showed auditory percepts in response to oCI stimulation. Regarding the clinical translation, further research is needed to establish a reliable and safe transduction of mature SGNs, which were shown to be significantly less sensitive to optogenetic transduction. To avoid phototoxicity, the use of long-wavelength light should be preferred.

In summary, we demonstrated that both the optogenetic stimulation and the development of oCIs have achieved important breakthroughs. The principle of optogenetic stimulation of the auditory pathway offers a high potential for future application in hearing restoration.

Invited Recorded Talk

1351: USING HAPTIC STIMULATION TO ENHANCE AUDITORY PERCEPTION IN COCHLEAR IMPLANT USERS

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Cochlear implants (CIs) allow many users to achieve excellent speech understanding in quiet listening conditions, but most struggle to understand speech in noisy environments and to locate sounds. This talk will present our recent work showing improvements in speech-in-noise performance and sound localisation when the electrical CI signal is supplemented using haptic stimulation on the wrists (“electro-haptic stimulation”). In our first study, we provided the speech amplitude envelope through haptic stimulation, which was extracted from the speech-in-noise signal using a signal-processing approach suitable for use in real time on a compact device. After 20 mins of training, participants were found to be able to identify 8% more words in noise with electro-haptic stimulation than with their CI alone. In our second study, we extracted the speech amplitude envelope from the audio received by devices behind each ear and delivered it through haptic stimulation on each wrist. This allowed us to transfer spatial-hearing cues. The unilateral CI users in our study were shown to have substantially improved sound localisation with electro-haptic stimulation, achieving performance comparable to that of bilateral hearing-aid users. In future work, we hope to develop a compact wrist-worn device to deliver haptic stimulation to CI users in the real-world. This could have an important clinical impact, providing an inexpensive, non-invasive means to improve speech-in-noise performance and spatial hearing.

Acknowledgements
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Signal Processing – Invited Speaker Abstracts

Invited Recorded Talk

1521: INVESTIGATING CAUSAL MECHANISMS OF SPEECH PERCEPTION WITH COCHLEAR IMPLANTS: FINDINGS WITH SPECTRAL BLURRING

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Most cochlear implant (CI) listeners experience difficulties in perceiving speech in situations with interfering sounds. This is partly due to current spread between the stimulating electrode channels, leading to wide neural excitation patterns and detrimental channel interactions. Reducing channel interactions may therefore lead to improved speech perception with CIs. However, this has not yet been achieved and mixed results have been reported for strategies that manipulated the electrical stimulation patterns. We conducted a series of experiments to investigate the causal effects of channel interaction by using spectral “blurring” as a simulation of increased spread of excitation. We measured effects on speech intelligibility: (1) for different types and degrees of blurring, (2) when applied to all or subsets of channels, (3) using equally spaced or clustered channels along the electrode array and (4) to determine blurring thresholds for individual listeners.

As expected, we found that increased channel interaction due to spectral blurring degraded speech perception with CIs. However, this was only the case when all electrode channels were affected and surprisingly not when only a subset of spaced channels was affected. Further, we found that even when deactivating the subset of blurred channels, there was no apparent degradation in performance. When all electrode channels were blurred by increasing amounts, speech perception thresholds worsened only beyond some value. That value differed between listeners and correlated with their performance on a spectro-temporal test and speech performance with the clinical-like map. There were differential effects for blurring at different segments of the electrode array, with a significantly stronger degradation of speech intelligibility when the most apical cluster of electrodes was blurred. Finally, blurring effects were consistent for two different types of background noise and even for speech in quiet with a different speech corpus.

Spectral blurring revealed some surprising findings, such that even large amounts of blurring do not seem to harm CI speech perception when equally spaced electrodes are affected, or when these are clustered at the more basal end of the array. These findings should inform electrode-deactivation strategies that build on surrogates of spread of excitation. Individual blurring thresholds revealed differences between listeners that were associated with their listening performance and could be used to identify listeners that may benefit most from strategies that aim to reduce channel interactions. We propose that causal manipulations such as spectral blurring could be used as a means to assess new stimulation strategies for CIs, for example those that aim to improve performance via more sparse stimulation patterns. This would avoid confounding differences between listeners and interactions within listeners in terms of spectro-temporal, linguistic and cognitive abilities.

Binaural/Bilateral/Bimodal/EAS – Invited Speaker Abstracts

Live Session Talk

1546: HOW DOES THE BRAIN COPE WITH BIMODAL LISTENING?

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Today a majority of CI listeners uses a hearing aid (HA) on their contralateral ear termed bimodal listening. Whereas listening with two ears has advantages, continued problems exist in situations that require binaural hearing, for instance when trying to understand speech in noisy conditions.

Our research focuses on bimodal hearing and uses speech audiometry, subjective ratings of auditory performance, and auditory evoked responses (AEP). AEP allow direct assessment of the cortical response. As some studies showed AEP changes to precede changes in behavioral performance, AEP findings may even guide auditory rehabilitation.

In a speech perception task in noise, the N1-P2 response of bimodal listeners approximated that seen in age-matched normal hearing controls (NH) within 6 months post-implantation, whereas a later N2/N400 response that was exclusive to the bimodal listeners did not reduce. eLORETA source localization demonstrated brain activation related to the N2/N400 in frontal areas including inferior frontal gyrus(1).

When comparing monaural to binaural listening, the N1 potential showed similar amplitude and latency differences between listening conditions for CI users at 6 months post-implantation and for NH, but source localization indicated that activation patterns differed between groups. In NH, differences between monaural and binaural listening localized to auditory cortex ipsilateral to the ear active in the monaural condition. In contrast, in CI listeners, activation in auditory cortex did not differ between monaural electric and bimodal listening. However, differences were observed bilaterally in extended areas of the frontal and parietal lobes and in ipsilateral temporal lobe, i.e. in brain areas associated with speech processing (2).

Results of the bimodal listeners suggest loss of lateralization in auditory cortex and excessive processing in speech-relevant cortex, which may be a correlate of the listening effort reported by bimodal listeners. It remains to be shown, whether this activation is reduced by auditory training, and whether a reduction translates into better auditory performance.

(1) Balkenhol T, Wallhäusser-Franke E, Rotter N, Servais JJ. Front Neurol. 2020; 11:161.
(2) Balkenhol T, Wallhäusser-Franke E, Rotter N, Servais JJ. Front Neurosci. 2020; 14:586119.

Live Session Talk

1533: EMERGENCE OF BINAURAL CUE SENSITIVITY IN PEDIATRIC CI RECIPIENTS WITH ACOUSTIC HEARING PRESERVATION

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Vanderbilt University Medical Center, Nashville, TN, USA

Cochlear implantation with minimally traumatic surgical techniques and atraumatic electrode arrays has led to an increasing number of cochlear implant (CI) recipients with the potential for combined Electric and binaural Acoustic Stimulation (EAS). Multiple groups have demonstrated that adult EAS listeners exhibit significant benefit for speech understanding in noise and spatial hearing tasks as compared to a CI paired with a contralateral HA. Further we have demonstrated that sensitivity to interaural time differences (ITDs) and interaural level differences (ILDs) is significantly correlated with EAS benefit for postlingually deafened adult EAS users. Despite this active phase of discovery in adult EAS users over the past two decades, there is a striking paucity of research on EAS outcomes in pediatric CI recipients, the expected trajectory of benefit following initial EAS fitting, and the development of binaural cue sensitivity in pediatric EAS listeners. In this presentation, we will describe our current research for pediatric EAS listeners on tasks of binaural cue sensitivity and EAS benefit for speech recognition in diffuse and spatially separated noise including the magnitude of EAS-related benefit on speech understanding in children with preserved acoustic hearing. Additionally we will describe recent data demonstrating the emergence of binaural cue sensitivity in children following a period of chronic EAS use. The clinical application of these data will be discussed including the need for regular monitoring of acoustic hearing preservation following cochlear implantation, greater acceptance of acoustic amplification for all ears with aidable residual acoustic hearing, and greater expansion of pediatric CI candidacy for children with precipitously sloping high-frequency hearing losses.

Live Session Talk

1349: INTERAURAL STIMULATION TIMING MISMATCH IN BIMODAL LISTENERS: EFFECT ON SOUND SOURCE LOCALIZATION AND SPATIAL UNMASKING OF SPEECH

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In bimodal cochlear implant (CI) / hearing aid (HA) users a constant interaural time delay in the order of several milliseconds occurs due to differences in both, signal processing and sites of stimulation of the devices. For MED-EL CI systems in combination with different HA types, we have quantified the respective device delay mismatch which is typically in the range of 3 to 10 ms with the CI stimulation preceding the HA stimulation. In recent years we have investigated the effect of this temporal mismatch on spatial hearing. We compared sound source localization in actual bimodal listeners with their original stimulation timing with a situation in which the device delay mismatch was reduced. The reduction was achieved by delaying the CI stimulation. For this, we used a self-designed and programmable external delay line. Results revealed that sound source localization improves significantly when the device delay mismatch is reduced even after years of bimodal provision, suggesting that the brain is unable to compensate for such an interaural timing mismatch. Recently, MED-EL introduced the CI delay as a new fitting parameter. Thus, this feature is now clinically available. However, the question how to optimally adjust this parameter patient-specifically has not yet been fully answered. During my talk I will go into detail how estimates of this delay value can be determined. Further, I will show that both, trueness and precision of sound source localization improves when the modalities are temporally aligned. Finally, the effect of the device delay mismatch on spatial unmasking of speech will be addressed.

Invited Recorded Talk

1517: FREQUENCY-TO-PLACE MISMATCH IN ELECTRIC-ACOUSTIC STIMULATION DEVICE USERS: EFFECTS ON SPEECH RECOGNITION AND MODIFIED MAPPING PROCEDURES

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Cochlear implant (CI) recipients with hearing preservation experience improved speech recognition with electric-acoustic stimulation (EAS) as compared to preoperative performance with a hearing aid or postoperatively when listening with the CI-alone. Despite the trends for better performance with EAS, outcomes across individuals are variable. These individual differences may be due in part to the wide variability across CI recipients in the angular insertion depth of the electrode array, which is related to the array design, cochlear morphology, and surgical approach. The EAS default mapping procedure does not consider array placement relative to the cochlear place frequency, resulting in frequency-to-place mismatch in the majority of EAS users. Mismatch has been shown to negatively impact the speech recognition of CI-alone users, although some CI-alone users demonstrate the ability to acclimate to mismatch with prolonged listening experience. For EAS users, mismatch may be particularly problematic because acoustic stimulation is resolved at the natural cochlear place, while the electric stimulation is spectrally-shifted. Better speech recognition may be observed for EAS users listening with a place-based map that aligns the electric filter frequencies to the cochlear place frequency to eliminate mismatch. The present investigation assesses the speech recognition of EAS users listening with either default or place-based maps within the initial months of device use to determine the influence of mismatch on early performance growth.

Adult CI recipients with low-frequency hearing preservation were randomized to receive maps with either the default filters or place-based filters at initial EAS activation. Subjects listened exclusively with either default or place-based maps and completed speech recognition tasks at initial EAS activation, and at 1, 3, and 6 months post-activation. Speech recognition tasks included vowel recognition and consonant-nucleus-consonant (CNC) word recognition. The vowel recognition stimuli were presented via direct audio input at a comfortably loud volume. The CNC words were presented in the sound field at 60 dB SPL with masking presented to the contralateral ear, when warranted. Performance for both tasks was scored as the percent correct. The frequency-to-place mismatch at 1500 Hz was estimated based on post-operative imaging.

Preliminary data suggest poorer speech recognition with greater magnitudes of mismatch. These data patterns were observed at the initial EAS activation interval and persisted through the 6-month post-activation interval. Investigation is ongoing to confirm these preliminary trends and to determine whether EAS users with greater magnitudes of mismatch eventually acclimate to the spectrally-shifted information and achieve similar speech recognition as observed for EAS users with little or no mismatch.

POSTER HALL:

Invited and Featured Recorded Talks + Posters

Machine Learning – Invited and Featured Talks + Posters

Invited Recorded Talk

1541: COGNITIVE-DRIVEN BINAURAL BEAMFORMING FOR HEARING DEVICES USING EEG-BASED AUDITORY ATTENTION DECODING

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During the last decades significant progress has been made in multi-microphone speech enhancement algorithms for hearing devices. Nevertheless, the performance of most algorithms depends on correctly identifying the target speaker to be enhanced. To identify the target speaker from single-trial EEG recordings in an acoustic scenario with two competing speakers, several auditory attention decoding (AAD) methods were recently proposed. Aiming at enhancing the target speaker and suppressing the interfering speaker and ambient noise, in this contribution we present a cognitive-driven speech enhancement system, consisting of a binaural beamformer which is steered based on AAD and estimated relative transfer function (RTF) vectors of both speakers [1,2]. For binaural beamforming and to generate reference signals for AAD, we consider either minimum-variance-distortionless-response (MVDR) beamformers or linearly-constrained-minimum-variance (LCMV) beamformers. Contrary to the binaural MVDR beamformer, the binaural LCMV beamformer allows to preserve the spatial impression of the acoustic scene and to control the suppression of the interfering speaker, which is important when intending to switch attention between speakers. For a reverberant acoustic scenario with two competing speakers and diffuse babble noise, 64-channel EEG responses with 18 participants were recorded. The speech enhancement performance of the proposed system was evaluated in terms of the binaural signal-to-interference-plus-noise ratio (SINR) improvement. Furthermore, we investigate the impact of RTF estimation errors and AAD errors on the speech enhancement performance. The experimental results show that the proposed system using LCMV beamformers yields a larger decoding performance and binaural SINR improvement (in the range of 4 to 7 dB) compared to using MVDR beamformers.

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[1] A. Aroudi, S. Doclo, Cognitive-driven binaural beamforming using EEG-based auditory attention decoding, IEEE/ACM Trans. Audio, Speech and Language Processing, vol. 28, pp. 862-875, 2020.

[2] A. Aroudi, M. Delcroix, T. Nakatani, K. Kinoshita, S. Araki, S. Doclo, Cognitive-driven convolutional beamforming using EEG-based auditory attention decoding, in Proc. IEEE International Workshop on Machine Learning for Signal Processing, Espoo, Finland, Sep. 2020.

Featured Recorded Talk:
1453: GENETIC ALGORITHMS FOR OPTIMIZING ACOUSTIC MODELS OF COCHLEAR IMPLANT HEARING IN SSD-CI SUBJECTS

Ariel Edward Hight, Nicole H. Capach, Jonathan D. Neukam, Sean K. R. Lineaweaver, Mahan Azadpour, Elad Sagi, Robert C. Froemke, Mario A. Svirsky
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Cochlear Implant (CI) stimulation is significantly distorted compared to acoustic stimulation in healthy ears. We are investigating the nature and extent of that distortion by having single-sided deaf (SSD) cochlear implant users select an acoustic representation (delivered to their normal ear) that provides the best match to what they hear through the cochlear implant. We have found that it is possible to obtain listener-selected models that have a high degree of similarity to the CI and result in similar levels of speech perception as the CI. The listener-selected models depend on electrode insertion depth and time after implantation for a given individual yet there are large differences across listeners (Capach et al. 2020). We want to ask whether it is possible to obtain even more precise acoustic models by exploring acoustic carriers other than the typically used tones and narrowband-noise (e.g., Hilkhuysen and Macherey 2014, and Grange et al. 2017). However, listener-driven exploration of the acoustic model parametric space (method-of-adjustment) becomes rapidly inefficient with increasing parameter spaces. Here, we developed a genetic algorithm for optimizing user-selected acoustic models and we examine its practical feasibility as well as noninferiority with respect to the traditional method-of adjustment procedure.

A genetic algorithm and user interface was developed for optimizing acoustic models and was based on software previously used for optimizing CI mapping (Lineaweaver and Wakefield 2011). Our combined software allows for testing acoustic model parameters, including but not limited to, low and high frequency cutoff (frequency-place mismatch) and the acoustic carrier. The initial evaluation of the software, reported here, tests the most common acoustic model carriers: tones and adjacent noise bands. The software initially randomizes a pool of acoustic models and the genetic algorithm uses a combination of principles of biological evolution such as gene crossover, selective insertion, and random mutation, which balance the exploration of large parameter spaces while leveraging users' selections.

As a first step, the genetic algorithm program has been successfully evaluated in SSD-CI users (n=8). The program converged to a single best acoustic model in 41 minutes on average. These acoustic models optimized by the GA were compared to traditional acoustic models where the analysis filters and synthesis filters had the same center frequency (i.e., no tonotopic mismatch), and to models optimized via traditional method-of-adjustment procedures (when available). Double-blind comparisons were done using a questionnaire to evaluate intelligibility, pleasantness, harshness, loudness, and overall similarity between the CI and the acoustic model. In all tested subjects, models optimized by the GA were deemed closer to the sound of the CI compared to traditional acoustic models, in all tested dimensions. Acoustic models obtained with the GA method were deemed at least as accurate as those obtained with the traditional method-of-adjustment procedure.

These results show that the new approach to explore acoustic model parameter spaces is feasible. Its main potential advantages are to minimize the bias inherent in method-of adjustment procedures and, most importantly, to increase efficiency of the parametric space search.

1312: A VERSATILE DEEP-LEARNING-BASED MUSIC PREPROCESSING SCHEME FOR COCHLEAR IMPLANT USERS

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Several studies have shown that CI listeners prefer music genres like country or pop music over complex genres like classical music and pieces with a small number of voices or instruments over bigger line-ups. An emphasis on the melody and on rhythmic elements and an attenuation of the accompaniment promote their access to music.

In this contribution we present a versatile source mixture model (SMM) that combines deep-learning based music source separation (DNN-SS) with harmonic/percussive source separation (HPSS). While both DNN-SS and HPSS have been applied in music preprocessing methods for CI listeners before, the proposed SMM allows individual mixtures of the harmonic and percussive portions of four sources, i.e. (sung) melody, drums, bass, and other accompaniment. For instance, an emphasis on the melody can be achieved while the rhythmic information from drums and bass is maintained and the harmonic and percussive parts of the remaining accompaniment are attenuated. Hence, a remix with a sparser spectral representation can be obtained which facilitates the transmission via the coarse electrical-neural interface of the cochlear implant. To this end, two different network architectures, a U-Net (Hennequin et al. (2020), JOSS, 5(50), 2154) and a MaD TwinNet (Drossos et al. (2018), IWAENC 2018, 421-425), were trained to remix the harmonic and percussive portions of each the four sources with particular weights using multi-track recordings taken from the MUSDB18 corpus (Rafii et al., (2017), zenodo.1117372).

An evaluation of the proposed SMM and both network types was performed with 13 normal-hearing listeners in conjunction with a CI simulation (Grange et al. (2017), JASA, 142(5) EL484-EL489). Eight 12-seconds long music extracts were selected based on a full-factorial experimental design with three factors and two levels per factor: “Singer gender” (male/female), “background vocals” (yes/no), and “music complexity” (low/high). Each extract contained vocals, bass, drums and other accompaniments. The experiment was conducted following a MUSHRA-type design with an open reference, a hidden reference, an anchor, and two different remix models for each network (i.e. six conditions to compare). We chose the unprocessed signal as the reference and the percussive signal component of the reference as the anchor. The ratings were measured on a category comparison rating (CCR) scale since it allows to indicate an improved, a degraded, or a similar signal quality.

A statistical analysis shows that the preservation of all source-wise percussive parts and the harmonic parts of vocals (and optionally drums) is rated significantly better than the reference and the anchor. Moreover, relative to the open reference and across all mixture models, complex music pieces were rated significantly higher after processing than less complex music pieces, whereas the average rating for the hidden reference was even slightly lower for complex music.

In conclusion, the proposed remixing technique offers a versatile music preprocessing framework allowing to adjust individual gains for the percussive and harmonic components of each source in a music piece. Remixing models which preserve the percussive components of all sources and the harmonic components of the main singing voice and drums have achieved the best performance and unfold their highest potential for complex music pieces.

This work has been funded by the German Research Foundation (DFG), Collaborative Research Center 823, Subproject B3.

1352: PHONEME-BASED TIME-FREQUENCY MASK ESTIMATION FOR REVERBERANT SPEECH ENHANCEMENT FOR COCHLEAR IMPLANT USERS

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Cochlear implant (CI) users experience substantially more difficulty in understanding speech in reverberant listening environments as compared to their normal hearing counterparts (Kokkinakis et al., 2011). A common speech enhancement technique is time-frequency (T-F) masking, where a matrix of gain values is applied to the T-F representation of reverberant speech to suppress reverberant reflections. Because the mask is unknown in real-time, an algorithm is required to estimate the mask using features extracted from the reverberant signal. Current algorithms typically estimate the T-F mask by applying machine learning models to a set of time-frequency features. The spectro-temporal structure of speech is highly variable and dependent on the acoustic environment, which can limit the ability of a mask estimation algorithm to generalize to unseen acoustic environments (Chazan et al., 2017).

One way to potentially overcome this variability is to incorporate knowledge of the phonemic structure of speech to better distinguish target speech from reverberant reflections. Phonemes are generally concentrated in specific frequency ranges, with vowels containing primarily low frequency content and fricatives containing high frequencies. Thus, we hypothesize that a phoneme-based algorithm can provide a more accurate estimate of the T-F mask. Furthermore, phoneme-based speech enhancement algorithms have improved the performance of automatic speech recognition models in reverberant environments (Wang et al., 2016), so we hypothesize that a phoneme-based approach to T-F masking may potentially benefit CI users.

We propose a phoneme-based T-F mask estimation algorithm, where a separate mask estimation model is trained for each phoneme. Using a remote testing framework, we conducted sentence recognition tests in normal hearing listeners to determine whether phoneme-based masks improve the intelligibility of vocoded speech in the ideal case where the phoneme is known exactly. The algorithms were tested in three reverberant environments: an office, a stairway, and a church. The results demonstrated higher phoneme recognition scores for speech enhanced using phoneme-based masks (office: 67.8±17.4%, stairway: 76.8±14.3%, church: 38.8±18.4%) than for speech enhanced using phoneme-independent masks (office: 53.3±18.4%, stairway: 55.2±19.6%, church: 25.9±17.1%). Future work will test the phoneme-based T-F mask estimation algorithm in the non-ideal case where the phoneme-specific mask estimation model is selected based on the prediction from a phoneme classification model.

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1474: A COMPARISON OF REAL-TIME FEASIBLE MASK ESTIMATION MODELS FOR REVERBERANT ARTIFACT REMOVAL IN COCHLEAR IMPLANT PULSE TRAINS

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Cochlear implant (CI) users experience far larger degradations in speech intelligibility in reverberant environments than their normal-hearing counterparts (Kokkinakis et al. 2011). Reverberation occurs when sound reflects off of surfaces in an enclosure, with reverberant reflections arriving at the listener at the same time as the direct speech signal. CI speech processing transforms the amplitude of frequency envelopes into discrete stimulus pulses across electrode channels. When the speech envelope is degraded by the simultaneous arrival of reverberant reflections, speech intelligibility is degraded. Particularly detrimental are late reverberant reflections which arrive at a listener after the termination of a phoneme and obscure the gaps between phonemes. Removing the reverberant artifacts between phonemes can restore speech envelope structure and significantly recover speech intelligibility for CI users in reverberation (Desmond et al. 2014; Kressner et al. 2018).

To remove reverberant artifacts between phonemes and restore the direct speech envelope, the technique of time-frequency (T-F) masking can be used to determine which time-frequency units of a degraded speech signal to retain or discard based on a measure of the local signal and interference energies within the speech envelope in frequency bands. In reverberant speech, T-F units between phonemes will contain predominantly late reverberant reflections and will be discarded. Typically, knowledge of the clean signal energy is unavailable to compute the ideal T-F mask, and so T-F mask values need to be estimated using information from the reverberant signal. Previous studies used statistical models to estimate mask values either by explicitly modelling late reverberant reflections (Hazrati et al. 2013a), leveraging a variance-based feature in an unsupervised manner (Hazrati et al. 2013b), or modelling vocal tract resonances using linear predictive coding (Hazrati and Loizou, 2013). While T-F masks estimated with these statistical models resulted in improvements in speech intelligibility in CI users, they required the use of non-causal information and empirical tuning of parameters, and the improvements shown were in limited, unrealistic reverberant settings. In addition, most of these approaches used time-frequency masking as a preprocessing step, using filter banks resulting in T-F decompositions with finer frequency resolution but coarser temporal resolution than that available in the CI stimulus. Due to the mismatch in spectro-temporal resolution, the T-F masks estimated with these models cannot be applied directly to the CI stimulus, imposing processing delays. Similar to T-F masking, we previously developed a machine learning algorithm to identify late reverberant reflections in CI pulse trains (Desmond, 2014). In this study, we develop additional machine learning models to estimate T-F masks with spectro-temporal resolutions compatible with the CI stimulus, enabling reverberation mitigation within the CI processing framework.

This study investigated the use of various machine learning models with different parametric complexities for estimating time-frequency masks for direct application within CI processing time frames using only causal features extracted from the reverberant signal. Our models are tested in reverberant conditions not encountered during training to test the algorithm's robustness. Preliminary results indicate models estimate masks with high accuracy when evaluated in reverberant conditions from the same room as used in training, although performance declines when tested on reverberant conditions from rooms not included during training. The algorithm performance, measured as the area under the receiver operating characteristic curve for the detection of speech-dominant mask values, will be reported. Additionally, we will report the resulting speech intelligibility of normal hearing subjects when tested with reverberant speech vocoded to simulate CI processing and mitigated by the investigated algorithms.

1479: CCI-MOBILE: AUTO-LSP BASED SPEECH ENHANCEMENT WITH COCHLEAR IMPLANT LISTENERS USING CONVOLUTIONAL NEURAL NETWORK CONSTRAINT MAPPING

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Speech perception in the presence of real-world distortion, such as competing for babble noise, is difficult for cochlear implant (CI) users due to the limited frequency resolution of speech produced with CI devices. One approach to address this issue is to suppress real-world noise without introducing processing artifacts into the speech signal that are perceived by CI listeners. Traditional speech enhancement algorithms such as MMSE have been shown to be effective in stationary noise, however, their application has limited success for non-stationary noise such as babble noise. Earlier unsupervised speech enhancement methods such as Auto-LSP (Hansen, Clements, 1991) and ACE-1: Auditory Constrained Enhancement (Nandkumar, Hansen, 1995) have been formulated which apply speech production and auditory based time-frequency spectral constraints to achieve improved overall speech quality. Recently, machine learning strategies have been shown to be successful in addressing such complex noisy environments. This study proposes to advance a previous Auto-LSP-based speech enhancement technique using a new strategy to apply constraints with a fully convolutional neural network (CNN) for cochlear implant users. The proposed algorithm calculates linear predictive coefficients (LPC) and line-spectral pair (LSP) parameters from each input signal frame over time. Inter- and Intra-frame constraints are then applied to line-spectral pair parameters to ensure that vocal tract characteristics do not vary widely from frame-to-frame overtime when speech is present. A fully connected convolutional neural network (CNN) is then deployed to predict the enhanced LSP parameters from their noisy versions. The proposed algorithm contains a limited number of parameters compared to traditional fully connected neural networks, which suggests a greater opportunity to transition to real-world CI/HA platforms. A large size speech training set is used to train the CNN network which ensures a powerful model capable of estimating the nonlinear mapping between noisy and clean speech via supervised learning. Finally, a constrained Wiener filter, present in the original Auto-LSP solution, is incorporated to predict the clean speech signal from the enhanced time-frequency speech constrained LPC parameters. Evaluation using objective measures suggests that the proposed algorithm achieves measurable improvement versus existing baseline systems, and therefore represents a viable option for implementation and field evaluation on the UTDallas CCi-Mobile research platform as a preprocessor.

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1505: CCI-MOBILE: COMPARATIVE ANALYSIS OF CNN-BASED MODELS VS HUMAN SOUND RECOGNITION AMONG COCHLEAR IMPLANT AND NORMAL HEARING SUBJECTS

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It has been previously shown that advantages in auditory processing exist when the following situational context traits or subject/system properties are present: (i) availability of a wider radial range up to 360 degrees, (ii) intolerance towards acoustic or visual obstruction, (iii) distant event horizon, (iv) availability for quick neural processing, (v) association of human attention and emotion, and (vi) activity during sleep. Sound Recognition (SR) is important in creating awareness regarding imminent environment danger and its role becomes even more pronounced in ensuring safety, enabling autonomy, and day-to-day ease among hearing-impaired individuals. Cochlear Implants (CIs) have been widely used as a solution to restore auditory function in hearing impaired individuals. SR among CI users is also an important measure used in the assessment in hearing-related quality of life. However to date, environmental SR among CIs has received very little attention and relatively few studies have investigated both assessment and impact relative to normal hearing (NH) subjects. These studies have reported large variations in SR performance and although, many of the findings from these studies are relatively inconsistent in methodology, experimental factors, and evaluation, the results broadly seem to suggest that there is a clear deficit in the existing CI sound processing to effectively process environmental sounds. In this study, a comparative analysis of NH and CI listeners is carried out to determine SR using classifiers trained on learned sound representations from a CNN-based sound event model. Audio files from the ESC-50 database were used as the sound battery to evaluate SR, where NH listeners were provided simulated CI listening conditions. Stimuli was provided via the CCi-MOBILE Research Platform to CI listeners and the Braeker Vocoder was used to auralize electric stimuli generated by CCi-MOBILE and synthesize the listening experience among CI subjects. Natural and auralized audio from ESC-50 were used to extract NH and simulated CI sound representations from a pre-trained CNN. A comparative analysis was performed to investigate the effect of machine models and subjective performance on SR performance. Metrics such as classification accuracy, F1-score, t-SNE based sound confusability feature-space analysis and others were used to perform a comparison of SR machine models for NH and CI listeners. It is suggested that findings from this study could be used to develop novel sound processing algorithms, identify optimal CI electrical stimulation characteristics for enhanced sound perception, and other key performance markers and characteristics necessary for advancing CI based environmental sound recognition (SR).

[1] Shekar, R.C., Belitz, C., & Hansen, J.H.L. (2021). Development of CNN-Based Cochlear Implant and Normal Hearing Sound Recognition Models Using Natural and Auralized Environmental Audio. IEEE SLT-2021: Spoken Language Technology Workshop, pp. 728-733.

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Physiology: Invited and Featured Talks + Posters

Invited Recorded Talk

1537: NEURAL TRACKING OF THE SPEECH ENVELOPE IN COCHLEAR IMPLANT USERS

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Electrophysiological measures in response to auditory stimuli have great potential for objectively assessing auditory functioning in cochlear implant users and fitting implant settings accordingly. However, current clinical applications are limited to using short, transient stimuli which target the periphery of the auditory system, such as the auditory nerve (ECAPs) or responses from the brainstem (EABRs). Responses to continuous stimulation at clinical rates, for instance, modulated tones (EASSRs) reflect frequency-specific higher-level processing in the auditory pathway. However, none of these techniques make use of ecologically valid stimuli such as natural running speech.

The temporal envelope of a speech signal, one of the most important cues for speech intelligibility, is tracked by the listener’s brain. Studies with normal hearing participants have shown that this neural representation of the envelope can be decoded from electroencephalograpic (EEG) recordings, and that the outcome of this decoding analysis relates to speech intelligibility. This forms the basis for a newly developed objective measure of speech intelligibility which can also be applied to cochlear implant users. Furthermore, this method enables assessment of speech envelope encoding in the auditory pathway, which is appealing to apply to cochlear implant users as current stimulation strategies mainly rely on encoding envelope information.

The major challenge in applying EEG-based neural envelope tracking methods in cochlear implant users is the presence of electrical stimulation artifacts originating from the cochlear implant itself. When presenting a speech stimulus at clinical rates, these artifacts are temporally overlapping. Furthermore, the stimulus artifacts contain the same modulated envelopes as the stimulus and are thus highly correlated with the targeted neural responses, making their interpretation challenging due to false positives.

In this contribution, we will present an overview of our work to translate neural envelope tracking methods to cochlear implant users. Using new techniques to reduce or avoid the effects of electrical stimulation artifacts, we demonstrated that envelope tracking can be measured in cochlear implant users, and that the obtained measures reflect the intelligibility of the speech stimulus. Efficacy of artifact removal is evaluated in multiple ways, for instance making use of subthreshold stimulation. Furthermore, interpretations of the envelope tracking models reveal interesting information about the temporal and spatial dynamics of how the electrically stimulated brain responds to speech.

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Invited Recorded Talk

1535: CORTICAL OSCILLATIONS REVEAL LOSS OF TOP-DOWN INTERACTIONS FOLLOWING CONGENITAL DEAFNESS

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Congenital deafness affects the functional and anatomical properties of the auditory system (Kral et al., 2019, Ann Rev Neurosci). It has been suggested that congenital deafness affects predominantly corticocortical functional connections within but also beyond the auditory system (the connectome model of deafness, Kral et al., 2016, Lancet Neurol). This may lead to increased risk of cognitive deficits in deaf children. Indeed, so-called induced responses, indicative of corticocortical interactions, were reduced in the auditory cortex of congenitally deaf cats (Yusuf et al., 2017, Brain). In the present study we directly investigated effective connectivity between primary and secondary areas of congenitally deaf cats (CDC).
In adult hearing cats (HC) and CDCs, responses to acoustic and electric stimulation (through a cochlear implant) were compared. Recordings were in the primary auditory field (A1) and the higher order posterior auditory field (PAF) using multielectrode arrays. Penetrations were histologically reconstructed. For effective connectivity pairwise phase consistency, weighted phase-lag index and nonparametric Granger causality were determined and compared.
CDCs demonstrated a substantially reduced stimulus-related corticocortical coupling in the connectivity measures used. Largest deficits were observed in sensory-related top-down interactions, in the alpha and beta band. The data document that corticocortical interactions are dependent on developmental hearing experience. In absence of hearing the effective connectivity reorganizes. This suggests that the congenitally deaf brain cannot incorporate top-down prediction information into auditory processing and thus have a deficient mechanism of predictive coding.

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Invited Recorded Talk

1542: VOLTAGE-GATED ION CHANNELS TUNE THE KINETICS AND SENSITIVITY OF SPIRAL GANGLION NEURONS

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The simple bipolar morphology of type I spiral ganglion neurons belies the underlying complexity of their morphological and electrophysiological phenotypes. Studies have shown, as with aspects of soma size and axon diameter, that action potential kinetics and neuron sensitivity vary both tonotopically and locally throughout the spiral ganglion. The myriad identified voltage-gated ion channels that contribute to the signature heterogeneous electrophysiological profile in the spiral ganglion are commensurately distributed as are their neurotrophin regulators. Moreover, the fine structure of action potentials generated experimentally with constant current pulses at the somata of type I neurons has also been observed in invading action potentials generated at nodes of Ranvier in the myelinated distal axon segment. This indicates that the highly-tuned analog components of action potentials are likely preserved as they propagate along myelinated axons to their central targets. Thus, the many classes of voltage-gated ion channels and their complex organization contributes to shaping the responses of spiral ganglion neurons. This process undoubtedly works in tandem with the prolific efferent innervation at the postsynaptic membrane, indicating that neurons receiving identical input are capable of generating distinctly different output. The resulting encoding strategy of dynamic heterogeneity, in which intrinsically-diverse electrophysiological properties of spiral ganglion neurons are actively regulated, results in the almost unlimited potential to shape neural signals as they are transmitted to higher auditory processing centers.

Featured Recorded Talk:

1346: ELECTROPHYSIOLOGICAL CHANGES AFTER FOCAL SPIRAL GANGLION NEURON LESIONS

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Speech perception in CI users is hampered by heterogeneous degeneration of spiral ganglion neurons (SGN) along an individual cochlea. The interpretation of human psychophysical and electrophysiological results is difficult, as reliable markers of locally restricted SGN degeneration/ survival are still missing. Recently, we have shown that the difference in responsiveness to cathodic versus anodic-leading stimulation (i.e. polarity effect, PE) corresponds to the presence of micro-lesions at the SGN soma, and may therefore be a marker for SGN loss (Konerding et al. 2020, Hear Res). The rationale of the PE (e.g. Miller et al. 1999, Hear Res) is a more central spike initiation sites for anodic than cathodic stimulation, which is proposed to change after lesioning. One limitation of our previous results is the use of biphasic pulses: the second phase of opposite polarity might have reduced or even changed the polarity effect.

Here for stimulation we used charged-balanced monophasic stimuli with an 8 times longer initial phase, prior to the 50µs-long dominant phase. We performed peripheral (electrically evoked compound action potentials) and central (inferior colliculus) recordings in 8 normal-hearing guinea pigs. The recordings were made prior and after an acute micro-lesion (<450µm diameter) was introduced in the basal part of the cochlea. To assess local changes, we compared apical and basal monopolar stimulation, using a 6-contact guinea pig-CI. The IC recording positions were chosen prior to neomycin-deafening, based on pure-tone stimulation.

The response profile in the IC showed the typical broad activation to monopolar stimulation. The first spike latency (FSL) was shorter for anodic than cathodic stimulation. ‘Off lesion’ electrode stimulation led to lower anodic than cathodic thresholds, both pre and post lesion. ‘On lesion’ electrode stimulation did, however, result in a significant change in the polarity effect after the lesion: After lesioning, the cathodic stimulation gained higher efficiency (lower thresholds) relative to the anodic stimulation. This corresponds to the previously documented PE shift after cochlear lesions.

We conclude that a) the FSL data confirmed a more central spike initiation sites for anodic than cathodic stimulation and b) the threshold PE is a marker for local changes in SGN health.

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1307: SPIRAL GANGLION-ON-A-CHIP

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Introduction: Hearing loss is the most widespread sensory disability in the world. Cochlear implants (CIs) are currently the most reliable hearing restoration strategy for patients with severe to profound hearing loss. CIs operate by bypassing the defective or lost cochlear hair cells, a common cause of hearing loss, and electrically stimulating spiral ganglion neurons (SGNs) directly. Thus, the outcomes of CIs depend on a population of excitable SGNs. The main issues affecting the performance of CIs are the reduced frequency resolution and the loss of spatial selectivity. Additionally, SGNs can degenerate and lose their functions with ageing or upon damage and do not regenerate spontaneously. To address these issues, a better understanding of how CIs interact with SGNs is required. This cannot be done in vivo as currently available models are significantly limited. Thus, there is a need for a reliable model that can serve to optimize CI performance and CI-SGN interaction.

Methods: In this project, we aim to develop a research platform that relies on growing SGNs on multielectrode (MEA) chips where we will be able to study the relationship between electrical and chemical stimulation parameters, which affect CI performance, and SGN behaviour. To achieve that, we first generated human induced stem cells (hiPSCs) from human skin cells (fibroblasts), and further induced them into otic progenitors. After induction, two morphologically distinct cell colonies were formed, namely otic epithelial progenitors (OEPs)- progenitors of hair cells- and otic neural progenitors (ONPs)- progenitors of SGNs. As we were interested in producing SGNs, ONPs and OEPs were separated, and ONPs were further induced to differentiate into SGNs. As a positive control, we developed procedures to grow spiral ganglion explants of neonatal rats in vitro. Following the expression of key markers via immunostaining and gene expression analyses, we started growing the rat spiral ganglion explants and hiPSC-derived SGNs on MEAs to assess the electrically mature phenotypes of hiPSC-derived SGNs via electrophysiology recordings compared to rat SGNs.

Results: Using immunostaining and RT-PCR, we confirmed that the neurons differentiated from hiPSCs were likely to be human SGNs. We also investigated the electrophysiological behaviour of hiPSC-derived SGNs on MEA chips comparing to rat SGNs. Our preliminary data showed that these neurons show spontaneous electrical activity and also respond to electrical stimuli. We are currently investigating SGN firing activity in response to varying electrical stimuli such as pulse duration, rate, shape and amplitude, which will ultimately enable us to improve CI efficacy.

Conclusion: In this project, we aim to develop platforms bridging the gap between the physiological context of in vivo studies and the advantages of in vitro manipulations, ultimately creating a spiral ganglion-on-a-chip. The human spiral ganglion-on-a-chip will ultimately allow us to investigate the impact of different stimulation parameters on SGNs and thus improve CI performance and validate computational models of the auditory nerve firing.

1350: IN-VIVO INNER EAR INFLAMMATORY RESPONSE DYNAMICS TO COCHLEAR IMPLANTS.

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Objective.
The present study aims to understand the inflammatory process of the inner ear following cochlear implant (CI) surgery in humans. Also, how the modulation of a single dose topic dexamethasone alters the overall immunological response in the cochlea.

Design.
To evaluate the inflammatory process triggered by electrode array insertion, we measured CI impedance and impedance subcomponents in a day-by-day basis between CI surgery and its activation. The growth pattern of the immune response was mathematically modelled, capturing the impedance dynamics pattern. Furthermore, we conducted a randomized double-blind placebo-controlled clinical trial to evaluate the effect of dexamethasone application.

Results.
The clinical impedance and impedance subcomponents showed different patterns between groups during the first week post implantation. Single-dose topical dexamethasone postponed (for ~3 days) but did not prevent the rise in impedance and its application was mainly affective at the base of the cochlea. The proposed mathematical model showed good fitting for all impedances and both modulations over time.

Conclusions.
The impedance subcomponents showed a close relationship with the biological processes of the foreign body reaction. The proposed mathematical model properly resembles the impedance dynamics in humans and their modulation due to the dexamethasone. Single-dose topic dexamethasone did not prevent the rise of impedance after CI implantation.

1355: DIFFERENT EFFECTS OF A FIXED CURRENT LEVEL ON TYPE I SPIRAL GANGLION NEURON DENSITIES ALONG THE COCHLEA

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The use of a wider electric dynamic range by increasing most comfortable levels (M-level) can be important for the outcome of cochlear implant recipients, since this is associated with better speech perception scores in quiet and noise (Robinson et al., 2012). However, the procedure could possibly lead to a current density which exceeded safe limits for spiral ganglion cell (SGC) health. Furthermore, it is largely unknown how the spread of electrical current affects SGCs at separate cochlear regions. The present study aimed to determine the SGC density along the cochlea upon chronic intracochlear stimulation with a fixed current level.

The first four or five electrode contacts of a HiFocus1j electrode array (Advanced Bionics HiRes 90k®) were inserted into the first turn of the left cochlea in 10 normal hearing adult female guinea pigs. After 4 weeks, an Auria© sound processor was fitted (HIRes strategy) with a pulse wide of 41.3 µs and a pulse rate of 1512 pulses per second. All unused electrode contacts were set to zero. The M-levels were randomly assigned to form three groups with: a low current stimulation intensity (“LSI”; mean M-level of 98.8 CU), a middle – (“MSI”; with a mean M-level of 148.8 CU) or a high current stimulation intensity (“HSI”; with a mean M-level of 235.1 CU). T-Levels were set at 10 % of M-levels. All animals were acoustically stimulated (16 h per day) with a radio play at 65 dB SPL. After 90 days of electrical stimulation, animals were perfused and the left modioli were decalcified, embedded in paraffin, cut into 6 µm thick slices and stained histologically with hematoxylin-eosin staining. The areas of the Rosenthal´s canals were determined and the numbers of SGC were counted.

The mean SGC density was calculated for every region (basal, medial and apical). In the basal part of the cochlea the SGC density was significantly lower in the “HSI”-group in comparison to the “LSI”- and “MSI”-groups. The medial area of the cochlea showed the significantly lowest SGC density for the “LSI”-group in comparison to the “MSI”- and “HSI” groups and the significantly highest SGC density for the “HSI”-group in comparison to the “MSI”-group. In the apical part of the cochlea the SGC density of “HSI”-group was significantly higher in comparison to the “LSI” – and “MSI”-groups.

The results show that a chronic high current stimulation leads to a significant SGC loss close to the electrode contacts (basal). However, the same stimulation had a protective effect for SGC´s in the medial and apical regions where the current density would be limited to lower levels. A low stimulation current does not affect spiral ganglion cell density in the basal area but was less protective than a higher stimulation current for the apical region. These data suggest the existence of an optimal current range for SGC protection and preservation.

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1364: ECAP POLARITY SENSITIVITY CORRELATES WITH PSYCHOPHYSICAL MULTI-PULSE INTEGRATION

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Previous research has shown that psychophysical thresholds as a function of pulse-train rate (termed either rate integration or multipulse integration) correlate with estimates of auditory neural survival in animal models. Specifically, steeper negative slopes of the integration function for rates below 1 kHz represent better neural health and shallower slopes represent poorer neural health. ECAP polarity sensitivity has also been used as a potential tool to characterize auditory neural health, where smaller differences in eCAP responses between polarities presumably reflect better neural health and larger differences reflect poorer neural health. The hypothesis for this study was that there would be a significant positive correlation between the slope of the integration function and eCAP polarity sensitivity, where steeper negative slopes and smaller eCAP polarity sensitivity values would both reflect better neural health. ECAP amplitude growth functions were obtained on all electrodes for both cathodic- and anodic-leading biphasic pulses in 15 recipients of Cochlear devices. Polarity sensitivity was quantified as the difference in normalized eCAP amplitudes across paired (anodic-cathodic) growth functions using a trapezoidal integration function. Multi-pulse integration functions were obtained on the same electrodes using a 2IFC procedure to obtain psychophysical thresholds for 300-ms pulse trains of 125, 500, and 1000 pps. Results showed a significant positive correlation between polarity sensitivity and the slope of the rate-integration function ($r = 0.223$, $p = 0.005$), which supported the hypothesis that greater polarity sensitivity and poorer integration ability (shallower slopes) both reflect poorer neural health.

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1417: EFFECTS OF COCHLEAR IMPLANT INSERTION ON THE FREQUENCY RECEPTIVE FIELDS IN THE PRIMARY AUDITORY CORTEX OF GUINEA PIG.

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In human, cochlear implant (CI) can successfully restore hearing in cases of profound deafness. Over the last years, patients with residual hearing were often implanted with electro-acoustic stimulation (EAS devices) and in that case, it is crucial to preserve their remaining hearing abilities. We examined here, in an animal model, to what extent inserting a cochlear implant in the tympanic ramp significantly altered the evoked responses and the frequency receptive field in the primary auditory cortex. Experiments were performed in anesthetized guinea pigs (6-18months old) with normal hearing. The tonotopic gradient of the primary auditory cortex (AI) was established by inserting a matrix of 16 cortical electrodes (2 rows of 8 electrodes separated by 1mm and 350µm within a row). The cortical depth was adjusted to optimize the detection of the tonotopic gradient. Multiunit activity (MUA) was collected while delivering pure tones and the Frequency Response Areas (FRA) were tested from 0.14kHz to 36kHz from 75 to 5dB. A simplified version of a cochlear implant (300µm in diameter) with 6 stimulating electrodes was then inserted in the cochlea via a cochleostomy (400µm in diameter) performed at 1.5mm from the round window (5 electrodes inserted in the 1st basal turn) and its connector was secured on the skull. The cortical electrodes were placed back in auditory cortex at the same location as before the CI insertion. The frequency tuning at 75dB and the FRA were re-determined with the same set of stimuli. On control animals, the frequency tuning and the FRA were determined before and 30min after removing and putting back the cortical array without opening the bulla and inserting electrodes in the cochlea. The data obtained in 21 animals indicated that inserting CI in the tympanic ramp led to increase the cortical threshold (by 10-15dB) in the high (18-36kHz) and, to a lesser extent (5-10dB) in the mid-frequencies (9-18kHz). The thresholds were slightly improved (by about 5dB) in the low frequencies (0.14-3.8kHz). The evoked firing rate (FR) was modified in the opposite direction: the increases in threshold were accompanied by decreases in FR and the decreases in threshold were accompanied by slight increases in FR. These effects were not observed in controls animals. These data suggest that in our conditions CI insertion can impair residual hearing in the high and mid-frequencies, but the cortical responses to low frequencies seem to be preserved.

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1420: COMBINED EFFECT OF PULSE ASYMMETRY AND RAMPED PULSES ON AUDITORY CORTEX EVOKED RESPONSES IS FUNCTION OF THE PULSE POLARITY

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Cochlear implant (CI) is the most successful neuroprothesis and a large field of research is still working on improving its coding strategies. The stimulation mode, the pulse shapes and grounding schemes can have important consequences on the nerve excitability, electrode discriminability, spread of excitation and response strength. Here, we quantified the responses from auditory cortex neurons to stimulations delivered through a CI while modifying the pulse parameters such as the ratio of pulse asymmetry, the polarity of the first phase and the pulse shape. Experiments were performed in anesthetized guinea pigs (6-18months old). The tonotopic gradient of the primary auditory cortex (AI) was first established by inserting a matrix of 16 cortical electrodes. A 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 eight nerve fibers were then stimulated with 5 levels of pulse asymmetry, from 1/1 being a rectangular symmetrical pulse to 1/5 where one of the pulse phase amplitude is one fifth of the second phase (its duration was 5 times longer). The pulse shape was also modified from a current square shape to a current ramp shape with 5 angle values (88°, 86°, 84°, 82° and 80°). All pulses were generated at constant charge (24nC) by a dedicated stimulation platform.
When anodic-first pulses were used changing the slope from 88° (taken as reference point) to 80° reduced the evoked cortical responses. For each angle, introducing the 5 levels of asymmetry further reduced the evoked firing rate. When cathodic-first pulses were used, changing the slope from 88° (taken as reference point) to 80° also reduced the evoked cortical responses. However, for each angle, introducing the 5 levels of asymmetry tended to increase the evoked firing rate, as if in this configuration, the pulse asymmetry was counteracting the effects induced by the slope of the pulse.

These data indicate that ramped pulse shapes can reduce the evoked firing rate and the spatial activation in primary auditory cortex. Combining the ramped shapes with an asymmetry shape impacted the firing rate in a way that was function of the polarity scheme. Adding asymmetry to an anodic-first ramped pulse increased the magnitude of the reduction in evoked firing rate, whereas adding asymmetry to a cathodic-first ramped pulse tended to counteract the reduction in evoked firing rate.

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1424: ACUTE EFFECTS OF COCHLEOSTOMY AND ELECTRODE ARRAY INSERTION ON ELECTROCOCHLEOGRAPHY IN NORMAL-HEARING GUINEA PIGS

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Electrocochleography (ECochG) refers to the recording of the electrical activity of hair cells and the auditory nerve in response to acoustic stimuli. ECochG is increasingly used in cochlear implant (CI) surgery, in order to monitor the traumatic effect of insertion of the electrode array. However, the obtained results are often poorly understood. Here we aim to elucidate ECochG affected by acute trauma by performing cochlear implantation in normal-hearing guinea pigs while performing ECochG at multiple time points during the procedure.

Thirteen normal-hearing guinea pigs were anesthetized, tracheostomized, and artificially ventilated with 1-2% isoflurane in O2 and N2O (1:2) throughout the experiment. Acute cochlear implantation consisted of (1) retro-auricular bullostomy to expose the cochlear round window and basal turn, (2) hand-drilling of 0.5- or 0.6-mm cochleostomy in the basal turn approximately 0.5 mm from the round window, (3) insertion of a short (~4 mm) four-contact animal electrode array (Advanced Bionics). Before and after each of these steps, ECochG was performed using a golden-ball electrode in the round-window niche; after insertion array electrodes were additionally used. Acoustical stimulation (clicks and 0.25-32 kHz tones) and data acquisition was controlled using a TDT RZ6 and custom-made software. The ECochG signal was analyzed among others in terms of amplitude and threshold of cochlear microphonics (CM) and the compound action potential (CAP). The midmodiolar sections of the implanted cochlea of each animal were histologically analyzed.

For seven animals the cochleostomy severely affected the CAP and CM, while for the other 6 animals the CAP and CM were hardly affected. Histological analysis showed that the basilar membrane was severely affected in the first group, and unaffected in the second group. The CAP threshold shifts varied from 10 to 60 dB at high frequencies for the first group, and from 0 to 20 dB for the second group. After electrode insertion the responses for animals in both groups declined further: ~10 dB CAP threshold shift for the first group and ~35 dB for 3/6 animals of the second group. The other three animals of the second group maintained the same thresholds as before insertion. After removal of the electrode array the responses decreased slightly for all animals of both groups, showing final threshold shifts of 10 to 70 dB. Threshold shifts were observed not only for high frequencies for which an effect is expected (considering the basal location of cochleostomy and electrode array), but also, albeit to a smaller extent, for the lower frequencies (1 kHz and below).

ECochG is affected by both cochleostomy and subsequent insertion of an electrode array. The extent of deterioration of ECochG was associated with the severity of trauma by cochleostomy or electrode insertion. In addition, even though the cochleostomy is drilled in the basal turn and the electrode array does not reach beyond the basal turn, ECochG responses to the lower frequencies can be significantly affected as well. This implies that both cochleostomy and subsequent array insertion can affect the low-frequency residual hearing of CI recipients, even with relatively short arrays located basally in the cochlea.

1476: PRELIMINARY INTER-PULSE GAP EFFECT AND POLARITY EFFECT FINDINGS IN RELATION TO ACOUSTIC HEARING AND ELECTROCOCHLEOGRAPHY IN A GUINEA PIG MODEL OF COCHLEAR IMPLANTS

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There is significant variability in patient outcomes with cochlear implants (CIs), and one factor may be the neural health of the auditory nerve. One useful and non-invasive way to assess cochlear neural health in CI recipients is to record the neural response to electric stimulation using the CI electrodes. Specifically, one CI electrode can be used to provide electric stimulation while another electrode can be used for recording the electrically-evoked compound action potential (ECAP). The ECAP inter-pulse gap (IPG) effect on offset of the amplitude growth functions has been shown to correlate with spiral ganglion neuron survival in animal models (Ramekers et al., 2014). The polarity effect (PE), or the difference in threshold between positive (anodic) and negative (cathodic) dominated pulse trains, can also be recorded via the ECAP, and has been suggested by neural modeling to indicate peripheral neurite survival and myelination (Rattay et al., 2001; Resnick et al., 2018). However, it is not clear how residual hearing and hair cell survival affect the ECAP and PE measures.

In the current study, four normal-hearing but aged guinea pigs with age-related hearing loss were implanted with a CI in the left ear. After 8 weeks of recovery, three animals received 40 hours a week of electric stimulation for a period of 20 weeks; one animal received stimulation for a shorter time period of 14 weeks. The following measures were collected at 4 week intervals starting at 3 weeks after surgery. Auditory brainstem responses (ABRs) for tones at 1, 2, 4, 8, and 16 kHz and electrically-evoked ABRs (EABRs) were recorded to assess changes in acoustic and electric thresholds. Electrocochleography (EcochG) was also conducted using the CI electrode to record responses to tones at 0.25, 0.5, 1, 2, 4, 8, and 16 kHz in order to assess hair cell and auditory nerve function with acoustic stimulation. ECAP amplitude growth functions for 8 and 30 microsecond IPGs were collected in response to biphasic, anodic-first pulse trains to calculate the IPG slope and offset effects, and for 8 microsecond IPGs in response to biphasic, cathodic-first pulse trains to calculate the PE. Following the completion of the experiment, all animals were perfused and cochlear tissue was harvested for histological quantification.

Animals had varying degrees of hearing preservation with ABR threshold shifts occurring predominantly in the cochlear region near the electrode. EABR thresholds were stable or increased slowly over time. Interestingly, ECAP IPG effects were reversed in cases of greater hearing preservation. Specifically, the IPG effect showed the expected trends in animals that lost significant hearing, but showed an opposite effect in animals with hearing preservation, i.e. the 30 microsecond IPG had a higher threshold and smaller response amplitude than the 7 microsecond IPG. The PE threshold effect was smaller/better in animals with hearing preservation, with lower thresholds for ECAP responses to cathodic stimulation than to anodic stimulation, suggesting that hearing preservation predicts better neurite/myelin survival. EcochG showed proportionally more loss of the hair cell compared to the neural responses over time. These preliminary findings suggest that ECAP measures of neural health may behave differently when hair cells and peripheral neurites are present, and caution is needed in interpretation of these measures in cases of hearing preservation.

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Auditory Modeling – Invited and Featured Talks + Posters

Invited Recorded Talk

1548: 3D CURRENT SPREAD AND NEURAL MODELLING OF HUMAN COCHLEAE

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Accurate computational models of the electrically stimulated auditory system are crucial for unravelling the many intertwined factors that affect hearing performance with cochlear implants (CIs). It is mostly not possible to test the physiological effect of a single parameter in a CI user because the required procedure would be highly invasive, or the parameters form part of the same effect and can therefore not be separated in an experimental setup. In contrast, the majority of parameters are accessible and separable in a computational model. Computational models may consequently create a versatile and powerful platform to (i) investigate, analyse and test hypotheses about hearing phenomena on an individual user basis, and (ii) inform objective programming of the device and application of other interventions in the management and care of CI users.

At the core of computational models of the auditory periphery is the prediction of the 3D spread of stimulation current throughout the cochlear volume. It is known that current spread is affected by the anatomical and morphometric characteristics of an individual cochlea, i.e. 3D current spread is unique for each cochlea. There is still much work to be done on improving the accuracy of the mathematical representation of the detailed anatomy of living CI users' cochleae as the resolution of the source data is severely limited. Without an accurate representation of the various conductivity domains that constitute the volume conductor, the subtle differences that distinguish one CI user from another may be lost in the modelling domain and therefore limit the application of such models in clinical application. The first part of the presentation will review work in our group that focuses on computational reconstruction of the detailed anatomy of the cochlea from a subset of landmarks that are readily measured on low-resolution clinical images of a CI user's cochlea.

Once the current spread has been calculated, a variety of neural models exist to estimate the response to a particular stimulation. Physiologically-based neural models are preferred to translate predicted current spread to neural firing patterns as the interface between the two types of models is founded in the biophysical behaviour of the system. Two primary factors need to be accounted for in a model of the auditory nerve that is aimed at predicting user-specific responses. Firstly, the model should be able to predict the spatial and temporal response to electrical stimulation in general, and secondly, user-specific variations in neural health along the cochlea should be included. Both these requirements have been addressed with some success in numerous studies, but as for the anatomical models, neural models can also not capture all the subtleties of a specific user's response to intracochlear stimulation yet. The second part of the presentation will highlight work that has been done to include person-specificity in the neural models.

The overarching objective of our work on computational models is to support the development of tools that may be of use in person-centred care of CI users. It is envisioned that computational models will eventually be developed to a level where their clinical application becomes standard practice within the management and care of CI users. The presentation will conclude with a brief look at the application of the models in the management of CI users.

Featured Recorded Talk:

1387: COMPARING PHONEMIC INFORMATION TRANSMISSION WITH COCHLEAR IMPLANTS BETWEEN HUMAN LISTENERS AND AN END-TO-END COMPUTATIONAL MODEL OF SPEECH PERCEPTION

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Through the process of encoding and transmitting acoustic information through CIs, spectral and temporal information is greatly reduced, which degrades speech perception for CI listeners. Progress on methods to improve CI speech perception is restricted by the cost, time and logistical requirements to conduct research studies with human CI listeners, and results are often influenced by within and between-subject factors that are unrelated to raw information transmission. Computational models of CI speech perception can be used to more rapidly and objectively evaluate processing strategies and stimulation techniques that may improve information transmission in CIs. In order to succeed, these models must make use of similar phonemic cues to CI listeners. The aim of our research is to replicate phoneme-level CI speech perception patterns using an end-to-end computational model.

In this study, we combined a finite element model (FEM) of an implanted cochlea, a computational model of the auditory nerve, and an automatic speech recognition neural network (ASR) to generate predictions of CI speech perception. In the first set of experiments, we validated the first two stages of our model using CI transimpedance matrices measured in humans (Garcia et al, 2020), and electrophysiological single-fibre animal data (Javel and Shepherd, 1987; Miller et al, 2008). In the second set of experiments, we trained and tested the ASR on neural activation patterns generated by the model, and evaluated the transmission of phonemic information using Information Transmission (IT; Miller and Nicely, 1955) and Sequential Information Analysis (SINFA: Wang, 1976). We then compared information transmission results to data measured in human CI listeners, using phoneme confusion matrices (Donaldson and Kreft, 2006; McKay and McDermott, 1993; Munson et al, 2003). The consonant features assessed were manner of articulation, place of articulation, and voicing, and the vowel features were the first formant, second formant, tenseness, and duration. In the final analysis, we used the model to investigate the degradation of mutual information through the CI signal processing chain, in order to identify the bottleneck of the information flow.

Results. In the IT analysis, paired t-tests revealed no significant differences between the model and the CI listener data for any vowel or consonant feature. For consonants, consistent with CI users, manner and voicing cues were transmitted better than place cues, although place cues still conveyed a higher proportion of the total information than voicing cues. A significant correlation was found between model predictions and CI user data for consonant recognition accuracies ($R = 0.641$, $p = 0.001$), suggesting that the model is able to capture between-consonant differences in perceptibility. For vowels, both the model and CI listeners prioritized the first and second formant cues to differentiate between vowels. The SINFA results revealed some discrepancies between the model and CI listeners, with the model making better use of place cues than CI listeners, and less use of the voicing cue. Additionally, the SINFA results showed that the model had difficulty using the vowel duration cue compared to CI users, potentially due to quantization by fixed-duration analysis windows. Finally, the analysis of IT at different stages in the CI processing chain showed that the bottleneck of information flow occurs at the electrode-neural interface.

1328: IMPACT OF AUDITORY NERVE FIBER'S DIAMETER ON THE DYNAMIC RANGE DURING STIMULATION WITH A COCHLEAR IMPLANT

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Introduction. The contribution of each single auditory nerve fiber (ANF) to the perception elicited with a cochlear implant (CI) depends on its spike probability. This spike probability as a function of the stimulus intensity is a sigmoid curve that can be quantified by its dynamic range. The dynamic range is defined as the intensity range over which spike probability increases from 0.1 to 0.9 [1]. This measure is comparable to 'relative spread' (measured in %) as introduced by Verveen as the quotient of spread (standard deviation of the distribution function) and threshold (50% spiking probability), and it was shown that RS is quite independent on pulse duration. However, RS is inversely related to the fiber diameter (thin fibers are noisy) [2]. Human ANFs have about doubled diameters in the central region (axon) compared to their dendrites [3, 4]. Moreover, during hearing impairment, dendrites reduce diameters down to 0.3 µm [5]. The question arises whether large variations in dynamic range as observed by Shepherd and Javel in deafened cat [1] can be explained by diameter variations in ANFs.

Methods. Ion current fluctuations across the cell membrane are assumed to be the key contributor to stochastic spiking. As the initiation of a spike depends on sodium current influx, we used a simple noise current approach introduced by Rattay [3], which allows us to evaluate all neural substructures (compartments of the cell) with the same method and is exceedingly computationally very efficient. A Gaussian noise current proportional (knoise = 0.001) to the square root of the number of its sodium channels (defined by sodium conductance gna measured in mS/cm2) was added every 2.5 µs to every compartment of the ANF model. We assumed that the center of the electrode is at a distance of 510 µm to an ANF, and the action potential is either generated in the dendrite or in the axon.

Results. For a human standard case of type 1 ANFs with 2 µm dendrite diameter and a doubled axon diameter of 4 µm the RS resulted in 14.05% and 9.46% for dendrite and axon, respectively for internodal length of 100 µm. In general, this approach shows that RS in myelinated axons follows a negative log(RS) to log(diameter) relationship as observed by [2]. Variations in internode length play a role specifically in thin fibers. The rather short non-myelinated presomatic segment had a quite small impact compared to the rather large diameter ratio axon/dendrite. The extreme case diameter ratio (0.3 µm dendrite, 4 µm axon) resulted in a RS ratio of 0.44/0.0946 = 4.65.

Conclusion. Dynamic range was reported to be larger for degenerated vs. healthy ANFs in cat [1]. However, the observed large variations in dynamic range (0.54dB up to 7.23dB relative to 1 µA) cannot be explained by the variations of diameters alone. Because the shortly deafened cats did not show the large variations in diameters we have seen in humans, but due to degeneration, irregular ion channel densities or failures in channel performance may contribute to the large variations in [1].

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1334: INVESTIGATION ON PERIPHERAL DEGENERATION OF HUMAN COCHLEAR NERVE FIBERS IN INTRA- AND EXTRACELLULAR STIMULATIONS

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Introduction. The sophisticated structure of the inner ear provides a sense of hearing that is possible by transmitting the auditory signals from cochlear sensory hair cells that travel through the myelinated auditory nerve fibers (ANFs) to the cochlear nuclei in the brain stem. An imperfect auditory system causes an interruption in the spiking pattern that will change the output. As an alternative, cochlear implants (CI) compensate for the defective pathway by stimulating the survived ANFs, extracellularly. However, clinical data shows a broad variation in CI outcomes between recipients, even with a similar level of hearing loss. Our latest investigation aimed to understand the origin of some of the outcome variations [1].

Methods. In the first part, peripheral diameter and myelination thickness of the ANFs from four human cochleae with different hearing levels were evaluated and later on were added to Rattay's multi-compartment model [2]. In the second part, we used our finite element model of a three-dimensional human cochlea with real ANF pathways as well as two CI arrays, one lateral and one perimodiolar, from our previous studies [1,3]. The investigated ANFs were stimulated once intracellularly to mimic the natural synaptic excitation of the inner hair cells and once extracellularly with the active electrodes from the investigated CIs.

Results. The normal hearing specimen demonstrated unimodal peripheral diameter and myelination thickness distributions, whereas the hearing loss cases displayed a multimodal distribution. Interestingly, numerous extremely thin fibers with diameters smaller than 0.5µm were detected in the extreme hearing loss case. For thin fibers (< 1µm), spike transfer to higher processing centers decreased dramatically, and action potential propagation blocked totally at the soma for fibers thinner than 0.3µm. Despite the easy excitability in intracellular stimulation, the signal needs a longer time to load the high capacity of soma. We observed large latencies and jitters in the simulated neural status spiking patterns based on our clinical data for different cochlear regions with different hearing loss levels.

Moreover, in extracellular stimulation, we studied the responses of the closest neuron identified as target neuron (TN) to five selected electrodes from each CI system. For this study, we considered three peripheral diameters of 2µm, 0.5µm, and without peripheral as normal, moderate, and progressive degeneration levels, respectively. Depending on the CI system, peripheral degeneration level, and the cochlear turns, by applying the TN threshold currents to the investigated electrodes, different groups of neurons from other regions were stimulated simultaneously.

Conclusion. We found lower threshold currents and higher focal stimulation in the perimodiolar CI, particularly in the middle and apical cochlea turns in moderate and progressive degeneration levels. Our findings were in agreement with clinical recordings [4,5].

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1347: NEURONAL EXCITATION PATTERNS IN TWO COCHLEA MODELS BASED ON HIGH-RESOLUTION MICRO-CT SCANS

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The human cochlea is a coiled and fluid-filled bony structure that sits in the petrous pyramid of the temporal bone. On average, it has a size of approximately two and three-fourth turns, and at the same time, shorter and longer variations have also been reported. It has been speculated that anatomical variations may influence the performance of cochlear implants (CI); however, there are few relevant studies in the literature. Here we investigate the effects of anatomical variations by analyzing finite element (FE) cochlear models for different subjects.

High-resolution micro-CT scans with an isotropic voxel size of 15 μm were taken from two human temporal bones. From each set of scans, regions of interest in the inner ear were segmented, including scala tympani, scala media, scala vestibuli, and the vestibulocochlear nerve (combined with a part of the facial nerve). A CI electrode based on the FLEXSOFT design by MED-EL was inserted into the scala tympani of both cochlear models. The cochlear models were then separately placed in the petrous pyramid of the skull of a human head model. The CI reference electrode with a diameter of approximately 1 cm was placed extracochlearly on the temporal bone of the same side as the CI. After the FE mesh was generated for the two combined cochlea-head models, they were imported into COMSOL Multiphysics for the simulation of electrical stimulation. Auditory nerve fibres were reconstructed inside the cochlear nerve, and the electric potential along the fibres was extracted. Excitation of the nerve fibres was simulated using a cable model.

On the one hand, our simulation results showed similar features between the two cochleae like the broad spread of excitation, cross-turn stimulation and very “rough” excitation patterns. On the other hand, excitation patterns showed variations due to anatomical and geometrical differences between the two cochleae. For a quantitative analysis of typical variations of neuronal excitation patterns between subjects provided with cochlear implants, we will need a larger variety of cochlear scans for FE models and more data on individual degeneration patterns of the cochlear nerve.

1348: SIMULATION OF ELECTRICAL EXCITATION PATTERNS WITH DEGENERATING AUDITORY NERVE FIBERS

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In cochlear implant recipients retrograde degeneration of auditory nerve fibers (ANFs) has been demonstrated. Therefore studies that modelled the effects of degeneration partially removed the peripheral processes. Recent experimental observations have indicated that degenerated ANFs manifested also a reduced diameter in their peripheral processes.

We simulated a population of 400 ANFs inside a 3D implanted cochlear model. Biphasic (cathodic-phase-first) pulses were delivered from one of the twelve pairs of electrode contacts in the array, with the reference electrode on the skull. ANFs were modelled as in Rattay et al., 2013. Three variations of the ANF population were simulated: (A) ANFs with full peripheral processes (before degeneration) (B) degenerated ANFs, peripheral processes removed (C) degenerated ANFs, peripheral processes with smaller diameter but original length. Firing characteristics of the ANF population were investigated.

Compared to undegenerated ANFs, increased thresholds were found in general with the degenerated populations, except with a couple of basal and apical stimulating electrodes the variation C exhibited a lower threshold than A. Thresholds for C were always lower than those for B, but differences were smaller than 1 dB. Similarly, a comparable dynamic range was found for both degenerated variations, and it was generally smaller than its undegenerated counterpart. In terms of the AP initiation sites, in contrast to the undegenerated population, both degenerated variations demonstrated more pronounced cross-turn activation as well as a higher number of central-process activation. APs were generated at similar stimulus levels for both degenerated populations; for B most APs were initiated in the soma, whereas for C the majority were triggered in the peripheral process directly before the soma, with the exception of a region in the middle of the cochlea where they initiated near the peripheral terminal. AP initiation in the beginning of the peripheral process showed approx. twice the latency for C compared to A.

In conclusion, neuronal excitation patterns to electrical stimulation exhibit similar traits between the two ways of modelling ANF degeneration. ANFs without peripheral processes may be considered as an extreme case of ANFs with very thin peripheral processes. Both modelling variations show degeneration of the peripheral processes causes rising thresholds and stronger cross-turn stimulation, which both degrade the performance of CIs.

1359: A POSSIBLE LEVEL CORRECTION TO THE COCHLEAR FREQUENCY-TO-PLACE MAP: IMPLICATIONS FOR COCHLEAR IMPLANTS

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Placement of cochlear implant (CI) electrodes within the cochlea is commonly listed as one of many factors contributing to variability in CI speech understanding outcomes. CIs are not completely inserted into the cochlea yet are programmed so that frequency ranges important for speech understanding are mapped to implanted electrodes. This frequency-to-electrode mapping can result in a tonotopic mismatch between frequency information delivered to electrodes and the frequencies associated with the neural elements they activate. Tonotopic mismatch can vary depending on anatomical factors such as electrode placement, cochlear size and the integrity of surviving neural elements. Current anatomical estimates suggest that in the first basal turn of the cochlea, CI electrodes deliver frequencies an average of one octave higher than frequencies associated with the putative spiral ganglion frequency-to-place map. Beyond the first turn, the tonotopic mismatch becomes more extreme depending on CI manufacturer. Although CI users can perceptually adapt and overcome this tonotopic mismatch, their adaptation may be incomplete which may impair speech understanding with their CI.

At the core of estimating tonotopic mismatch in CI users is reliance not only on Greenwood's near-logarithmic function relating cochlear place to frequency, but also on the specific parameter values he proposed for that function. These values were A=165.4, a=0.06, and k=0.88 or 1. However, some data sets were shifted basalward in comparison to cochlear positions suggested by these proposed parameters. Two possible explanations were offered for the discrepancy, 1) degradation of the cochlear preparation during measurement, and 2) maximal cochlear amplitudes were produced by frequencies lower than characteristic frequencies (CFs), i.e. those frequencies where cochlear locations are most sensitive. Although Greenwood favored the former explanation, there are several more current physiological data sets showing that frequencies associated with maximum cochlear amplitude (i.e. best frequency, or BF) are level dependent such that BF shifts to lower frequencies as sound level is increased. In other words, higher level sounds activate more basal cochlear regions than lower level sounds.

The purpose of the present study is to revisit Greenwood's frequency-to-place map in the context of level-dependent basalward shifts in BF relative to CF. Available physiological data will be examined to estimate the magnitude of these shifts, and a possible level-dependent modification to Greenwood's function will be suggested. Preliminary evaluation of physiological data suggests that estimates of tonotopic mismatch in CI users may not be as extreme as previously thought, particularly for more basal electrodes.

1380: A 3D COMPUTATIONAL MODEL FRAMEWORK FOR STIMULATION WITH THE AUDITORY NERVE IMPLANT AND THE COCHLEAR IMPLANT

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Background: A novel auditory prosthesis for direct intraneural electric stimulation of the auditory nerve (auditory nerve implant, ANI) is currently under development. The ANI consists of a Utah Slanted Electrode Array (USEA, Blackrock Microsystems) with penetrating electrodes connected to a MED-EL SYNCHRONY 2 stimulator and will be implanted into the auditory nerve (AN) between the cochlea and the brainstem. Due to the close proximity of the penetrating electrodes and the target nerve fibers, the ANI will potentially facilitate more focused stimulation than current hearing prostheses. To investigate the specificity of the ANI stimulation, a computational modeling framework was developed incorporating a simulation of the voltage distributions and a phenomenological neuron model. The framework was used to compare neural activation from a conventional cochlear implant (CI) with that from the novel ANI.

Methods: A realistic 3D finite element method (3D-FEM) model of the cochlea and the auditory nerve including auditory nerve fiber (ANF) pathways was created based on histological data. A model of a CI electrode array was inserted into the scala tympani and a USEA was placed in the AN such that the same auditory nerve model could be stimulated with both implants. The 3D-FEM model was used to simulate the voltage distribution along the ANFs when stimulating with the CI or the ANI. The activating function was derived from the voltage distribution and a phenomenological stochastic neuron model was applied to simulate excitation of the ANFs. The result was an excitation profile showing the activation of the ANFs over their tonotopic frequency. With this framework, excitation profiles were derived from all electrodes of the CI and the ANI at different stimulation levels. The specificity of the stimulation was evaluated based on the width of the peaks in the excitation profiles. A parametric analysis was performed to investigate the influence of several model parameters of the 3D-FEM model and the neuron model.

Results: For the ANI, the excitation profiles varied from single frequency peaks with a narrow spread of activation to multimodal profiles with multiple peak frequencies or very broad excitations. The number of peaks in the excitation profiles depended on the stimulating electrode and the anatomic and tonotopic organization of ANFs. For the CI, a single peak or an additional peak caused by cross-turn stimulation were observed. The peak widths mainly depended on stimulation level and electrical conductivity values of the 3D-FEM model.

Conclusion: A computational modeling framework was developed to simulate the excitation profiles of stimulation with a CI and the novel ANI. The results of this project will be used for the future development of speech coding and fitting strategies for the ANI clinical trial.

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1385: MODELING SPATIAL HEARING LIMITATIONS IN COCHLEAR IMPLANTS WITH A FOCUS ON THE BINAURAL INTERACTION STAGE

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Most bilateral CI users have demonstrated some degree of interaural time difference (ITD) sensitivity in controlled lab conditions with single electrode stimulation. However, their ITD sensitivity is limited to rates below 300-500 pulses per second, which is surprisingly low when considering the better auditory nerve (AN) phase locking to electric stimulation than to acoustic stimulation. Mechanisms underlying such limited ITD sensitivity in bilateral CI users are still poorly understood, partially due to the experimental differences across related studies. Computational simulation of the whole process could improve comparability and deepen our understanding of the functional relations. Specifically, it can quantify the influence of some experimental variations and it can be instrumental in developing and consolidating theoretical hypotheses.

Here we revisit a hypothesis proposed by Kelvasa and Dietz (2015, Trends in Hearing) that 1) the encoding of interaural cues with electric stimulation is most robust in case of excitatory-inhibitory (EI) processing as it is commonly observed in the lateral superior olive (LSO); 2) the high-rate ITD sensitivity from the medial superior olive (MSO) is corrupted or at least it does not provide behaviorally useful cues in many cases. We connected an LSO-type EI-model neuron (without MSO pathway) to either a model of the normal-hearing acoustic auditory periphery or to a model of the electrically stimulated auditory nerve. The resulting simulation framework was then used for quantifying the influence of stimulus parameters (e.g., stimulation level, stimulation rate), stimulus types (acoustic stimuli with different amplitude modulation shapes, unmodulated and sinusoidal amplitude modulated high-rate electrical pulse trains), and for comparing between acoustic and electric stimulation.

In general, the single EI-model neuron captured most features of the experimentally obtained response rate properties with electric stimulation, such as the shape of rate-ITD and rate-ILD functions, the dependence on stimulation level, and on pulse rate or modulation frequency dependence. Rate-ITD functions with high-rate amplitude modulated electric stimuli are very similar to their acoustic counterparts. Response rates obtained with unmodulated electric pulse trains are best resembled by acoustic filtered clicks. The fairly rapid decline of ITD sensitivity at rates above 300/s is correctly simulated by the 3.1 ms long inhibitory post synaptic conductance. We further demonstrate first examples of how an extended simulation chain, from the CI signal processing to central decoding stages, can help to understand how the complex interplay of numerous device and brain stages causes some of the limitations of spatial hearing with CIs.

1386: MODELLING AMPLITUDE-MODULATION DETECTION FOR COCHLEAR-IMPLANT USERS: AN INFORMATION THEORY APPROACH

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Computational models can help in understanding the limitations of cochlear-implant (CI) users when performing various hearing tasks. Models can be used to investigate the effect of parameters which cannot be easily manipulated experimentally in real CI users (e.g., neural health, current spread, insertion depth, etc.) on the amount of acoustic information transmitted to the auditory nerve. This could guide the design and fitting of CI sound-coding strategies. In this work, we first present a model of the auditory nerve response to arbitrary acoustic stimulation for CI users. In the model, the acoustic stimulus is first converted into sequences of electrical pulses (electrodogram) according to a selected processing strategy; a current spread model then describes how electrical current is distributed to auditory nerve fibers along the cochlea; finally, each fiber generates spike trains in response to the received electrical stimulation using the point-process model of Goldwyn et al. (2012). An information-theory algorithm is then used to assess the amount of information from the acoustic stimulus that has been transmitted to the auditory nerve. The algorithm aims at optimally reconstructing the acoustic stimulus from the simulated spike trains, and the quality of the reconstruction reflects how much information is contained in the simulated spike trains. To test and validate this framework, the model and reconstruction approach are applied to reproduce CI-user performance in an amplitude-modulation detection task using direct stimulation via a single electrode (data from Chatterjee and Oberut, 2011). It will be shown that a model with generic parameters is sufficient to predict the average experimental data. Auditory-nerve fiber density and current spread are varied to explore whether the model can reproduce individual data. Details of the model and methods will be presented and discussed.

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1396: AN ENCODING-DECODING METHOD FOR STUDYING PERCEPTION WITH HEARING LOSS

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Over the past decade, 'hidden hearing loss' – hearing difficulty in noisy environments, seemingly without accompanying audiometric threshold shifts – has inspired a wealth of research, including what and how morphological changes in the auditory periphery might give rise to this phenomenon. For example, the stochastic undersampling model (Lopez-Poveda & Barrios, 2013) suggests that auditory deafferentation can potentially introduce internal noise in the subsequent auditory processing stages. However, the parameters used in the original stochastic undersampling model do not capture the full complexity of physiological response characteristics, thus leaving unclear the quantity of information conveyed by the auditory nerve fibers. Here, we propose an expanded, physiologically more realistic encoding-decoding method that extends the stochastic undersampling model to study the perceptual consequences of auditory nerve fiber loss.

Stochastic undersampling is an encoding model of the auditory periphery; it models each auditory fiber as a sampler, which samples the input sound at its own stochastic rate, and the loss of auditory nerve fibers is mimicked by reducing the number of samplers. In our study, half-wave rectification, refractoriness, and three auditory nerve fiber types (low, medium, and high spontaneous rate) are added to the original stochastic undersampling model to better mimic the actual information transmission in the peripheral auditory pathway. In addition, an artificial-neural-network-based stimulus reconstruction is used to decode the modelled auditory nerve fiber responses back to an audio signal. This reconstruction contains a neural network whose architecture is based on Akbari et al.'s (2019) reconstruction of sounds from auditory cortex recordings and a speech synthesizer (Morise et al., 2016). Our encoding-decoding method explicitly models auditory nerve fiber (type) loss within a more realistic physiological setting, which allows us to relate the level of fiber loss to auditory perceptual changes in human listeners.

We conducted a pure tone (250, 1000, 4000 Hz) in noise detection task and a hearing in noise task (HINT) via MTurk. Pink noise (pure tone detection task) and speech-shaped noise (HINT task) were fixed at 65 dB SPL. The sounds used in these two tasks were degraded using the encoding-decoding model, implementing three different levels of auditory nerve fiber (ANF) loss (0, 90, 95%). Preliminary results indicate that the pure tone detection threshold in noise increases significantly with a decrease in the number of fibers, at a rate that aligns well with predictions from Oxenham (2016). For the HINT task, the results only showed a significant threshold shift between the 90% and 95% ANF loss conditions.

In conclusion, our model combines detailed physiological response properties with the stochastic undersampling model and thereby creates a more realistic computational model which can be used to test human listeners. Our encoding-decoding method enables artificial introductions of lesions in the peripheral auditory pathway (e.g. selective frequency loss, or fiber type loss) and thus can benefit the study of auditory pathology and cochlear implants.

1401: OPTIMIZED FITTING OF A STOCHASTIC AUDITORY NERVE FIBER MODEL TO PATCH-CLAMP DATA

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Having an accurate description of the patterns of action potentials (APs) generated in auditory nerve fibers (ANFs) by cochlear implants is important for understanding neural coding in electric hearing. Biophysical computational models are a powerful tool for capturing what is known about the electrochemical dynamics and ion-channel gating mechanisms underlying neural excitability.

Previous computational models of an ANF node of Ranvier suggest that low-threshold potassium (KLT) and hyperpolarization-activated cyclic nucleotide-gated cation (HCN) channels affect an ANF's absolute and relative refractory periods and produce adaptation/accommodation to high-rate pulse trains (Negm & Bruce, IEEE TBME 2014; Boulet & Bruce, JARO 2017). In recent work (Bruce et al, CIAP 2019, ARO 2020), we have explored the effects of another type of potassium channel that has recently been identified in mammalian ANFs, M-current potassium channels formed by Kv7.2 and Kv7.3 ion channel proteins (Kim & Rutherford, J Neurosci 2016). Like the KLT and HCN channels, the M current is active at the resting membrane potential of ANFs and has slower opening/closing dynamics than the AP-generating sodium and potassium channels and is thus expected to also have an influence over the short-term and long-term temporal response properties of ANFs. We have incorporated an M-current model used in other cell types (Lawrence et al, J Neurosci 2006) into the previous ANF model of Boulet & Bruce (JARO 2017). Preliminary results show that inclusion of the M current in the model better predicts the room-temperature ANF patch-clamp data of Rutherford et al (J Neurosci 2012) collected in response to a variety of stimuli, including long depolarizing and hyperpolarizing current steps and current ramp with a range of slopes and durations.

However, with such a large number of different types of stochastic ion channels, the model has a very high dimensionality making it difficult to manually adjust the model parameters to explain the data. We are now developing a framework to automate fitting of the model parameters to explain the ANF patch-clamp data of Rutherford et al. using a multi-objective optimization approach (Druckmann et al, Front Neurosci 2007). The protocol makes use of the Non-Dominated Sorting Genetic Algorithm-II (Deb et al, IEEE Trans Evol Comput 2002) implemented in the BluePyOpt open-source software package (Van Geit et al, Front Neuroinform 2016). However, creating the features and weightings to be used in the fitness function is not a trivial task and has a large impact on the resulting solutions. The proper features to be used and weightings is an area of ongoing work. Thus far, the most success has come from using a combination of peak heights, correlation, and linear modeling metrics. Preliminary results have shown that the M-channel plays an important role in the model and is most effective when many of the channels are open at rest. The M-channels appear to interact with other channels making the membrane response more variable and thus more effective at explaining the stochastic firing behavior observed in the recordings. The automated approach helps us explore the vast hyperdimensional parameter space and locate potential areas to effectively explain the observed behavior of the ANF with our model.

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1409: CAN THE EFFECTS OF AUDITORY NERVE DAMAGE BE ACCOUNTED FOR IN A COMPUTATIONAL ECAP MODEL?

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The survival and health of the cochlear nerve have been shown to affect the efficacy of a cochlear implant because of the impact it has on the conduction of electrically excited neural activity to the brain. Damage to the cochlear nerve can be divided into degeneration and demyelination. If cochlear neurodegeneration progresses to include the soma, the electrically stimulated nerve will no longer be able to generate an action potential. Demyelination will in turn impair the propagation of the action potential along the auditory nerve.

A number of studies have examined the possibility of using electrophysiological measures, such as electrically evoked compound action potentials (ECAPs), to determine the survival rate and health of the cochlear nerve. These studies examined various ECAP characteristics such as latency, amplitude and input-output functions.

This study first presents a condensed overview of the pertinent findings within the available body of literature concerning the plausibility of using ECAP measurements to determine the survival rate and health of the auditory nerve. It also provides access to information regarding a broad spectrum of types of neural damage and its subsequent projected effects on ECAP measurements.

Based on these findings, the study then constructed computational models to predict ECAP responses to varying degrees of neural degeneration and demyelination. A single straight auditory nerve fibre, as well as an elementary curved neural population model, were implemented in an infinite homogeneous medium. The ECAPs generated by both models generally show the expected responses to neural damage applied to the neural fibre models. The models also reflect the effect of various other factors, such as electrode placement and stimulus levels, on the ECAP responses. This study may support more accurate predictive modelling, simplify in vivo auditory neural health diagnoses and enable better interpretation of measured ECAP results.

1426: SPEECH-IN-NOISE PERFORMANCE OF SIMULATED COCHLEAR IMPLANT USERS IS SUBSTANTIALLY IMPROVED WITH SPECTRAL-MODULATION PRESERVING DYNAMIC RANGE COMPRESSION

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Cochlear implant (CI) users encounter profound difficulties when communicating in noisy environments. One reason for this may be their inability to exploit spectral and temporal gaps. Indeed, a significant correlation of a limited spectral resolution with deteriorated speech recognition performance was shown in numerous studies.

Recently proposed approaches to model aided impaired hearing with modified automatic speech recognition systems try to disentangle the underlying mechanisms which affect speech recognition performance. The aim is to eventually provide ways to represent speech information in a more supportive way.

In prior studies, the Framework for Auditory Discrimination Experiments (FADE) was shown to successfully incorporate hearing impairment with parameters to model absolute hearing thresholds, supra-threshold signal distortion by a level uncertainty, and spectral smearing.

In this study, indications for a feasible range of the simulation parameters to model the performance of CI users with FADE were inferred by comparing FADE predictions and results of actual CI users of two behavioral tests: the psychoacoustic spectral-temporally modulated ripple test (SMRT) and the speech-audiometric Oldenburg matrix sentence test.

The modified FADE model was then used to evaluate a new approach to dynamic range compression. The algorithm aims at compensating for the distortion-induced hearing loss by enhancing spectral modulations, which are suspected to improve speech understanding in noise beyond the limits of linear amplification.

The results show that the model parameter implementing a level uncertainty had a greater effect on simulated test performances than the spectral degradation. The finding supports the hypothesis of a predominant underlying distortion mechanism also in electrically stimulated hearing.

The effect of the distortion component was then targeted by the novel dynamic range compression scheme. Indeed, the preservation of specific spectral modulations using the algorithm improved the simulated speech recognition performance especially in a fluctuating noise and for a higher modulation-expanding factor by 7.3 dB. This indicates a potential to partially compensate for a supra-threshold distortion-induced hearing loss component and to thereby help to provide masking release for actual CI users. Empirical evidence is required to verify the feasibility of the model assumptions and to evaluate the here found simulated benefit in speech recognition performance.

1450: EXAMINING THE INTERPHASE GAP OFFSET EFFECT AND ITS RELATION TO NEURAL HEALTH IN A COMPUTATIONAL MODEL

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Changing the duration of the interphase gap (IPG) between the two phases of a symmetric biphasic stimulus is known to result in an offset in the amplitude growth functions of a CI electrode contact (Kim et al. 2010, Ramekers et al. 2014, Hughes et al. 2018). Since the magnitude of this IPG offset effect can vary both between and within individual patients, it has been suggested that it may be affected by the health of the auditory neurons, leading to the hypothesis that the IPG offset effect can be interpreted as a measure of neural health (Brochier et al 2020).

To test this hypothesis, a previously published computational model of a human cochlea implanted with an electrode array was used to simulate neural excitation with a range of symmetric biphasic and monophasic pulses (Kalkman et al. 2014, 2015). The model consisted of a Boundary Element Method based volume conduction model and a deterministic active nerve fibre model. The volume conduction model employed realistic three-dimensional representations of five human cochleae, implanted with electrode arrays in lateral, mid-scalar and medial positions and contained realistic nerve fibre trajectories, modelled in different stages of neural degeneration. In the active nerve fibre model, the auditory neurons were described as electrical double cables governed by the so-called Schwarz-Reid-Bostock neural kinetics scheme (Schwarz et al., 1995). The neural model was used to simulate neural responses due to electrical potential distributions calculated by the volume conduction model.

Increasing the IPG of a symmetric biphasic pulse in the model decreased simulated thresholds, which was consistent with reports in literature (Kim et al. 2010, Ramekers et al. 2014, Hughes et al. 2018). Surprisingly though, increasing the IPG often lowered thresholds below values expected from simulations of independent monophasic pulses, indicating that the two phases of the biphasic pulse were constructively interacting. This meant that increasing the IPG did not always lower thresholds by decreasing inhibition of one phase by the other, but that it was also achieved by the two phases ‘assisting’ each other. This occurred more often and more strongly for cathodic-first pulses than for anodic-first ones.

The IPG offset was found to be affected by the degree of neural degeneration, but no clear consistent effect was found. IPG offsets were also affected by electrode position, with contacts located deeper in the cochlea generally showing greater IPG offsets. However, the effects of electrode to modiolus distance were again inconsistent.

The main conclusion of this study was that although the IPG offset effect was affected by the state of the auditory neurons, it could not be reliably interpreted as an indicator of neural health, as other factors such as electrode insertion depth and position within the scala tympani obfuscated the outcomes.

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1468: INVESTIGATION OF THE IMPACT OF COCHLEAR IMPLANTS ON COCHLEAR ION HOMEOSTASIS USING A COMPUTATIONAL MODEL

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Cochlear implantation involves the insertion of an electrode array into the scala tympani, a fluid filled compartment that plays an important role in cochlear ion homeostasis. The insertion of a cochlear implant (CI) electrode will reduce the normally available fluid volume in the scala tympani in a manner that depends on electrode model and insertion depth. As the health of all tissues depends on maintaining appropriate ion and fluid gradients, it is essential to understand the effect of CI insertion on these processes. This is especially important for hybrid CIs that rely on short electrode arrays that are inserted to stimulate the auditory nerve in the basal regions of the cochlea for access to high-frequency sounds for patients with residual low-frequency hearing. However, the short electrode array still decreases the volume of the scala tympani and may disrupt the normal flow of ions in the low frequency regions at the apex of the cochlea. Maintenance of the normal flow of potassium ions and the endocochlear potential in the healthy regions of the cochlea is necessary for driving the depolarization of hair cells in response to sound stimuli to transduce the sound vibrations into nerve impulses that are sent to the brain via the auditory nerve. We have developed a computational model of ion transport in the cochlea that characterizes each the distinctive fluid-filled cavities, cells, and tissues of the cochlea to study ion transport and the overall potassium and sodium currents. The model enables simulation of the effects of energy depletion that could occur as a result of damage to the microcirculation. Here we investigate how reduction of the volume of perilymph in the scala tympani and damage to the cochlea during CI insertion are expected to impact overall ion and fluid homeostasis. Computational modeling of how ion flow throughout the whole cochlea enables sound stimuli transduction and maintains homeostasis is important for understanding how damage to this delicate system impacts hearing and may motivate the development of strategies to reduce tissue damage during invasive procedures such as CI insertion.

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Child Development – Featured Talk + Posters

Featured Recorded Talk:

1478: AN ELECTROPHYSIOLOGICAL STUDY OF AUDIOVISUAL SPEECH PERCEPTION IN CI-USING DEAF CHILDREN

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Naturalistic speech occurs under conditions in which access to both auditory (i.e. acoustic) and visual (i.e. facial) information is available. A large body of behavioral research shows benefits of audiovisual (A/V) over audio only (A) presentations in word recognition, lexical decision and sentence processing and under conditions of noise (Bernstein et al., 2004; Ma et al., 2009). Electrophysiological studies have sought to characterize the neural correlates A/V presented speech and have reported modulations of endogenous ERP components (e.g. P1/N1 & P2) and exogenous late potentials (e.g. N400) (Basirat et al., 2018; Brunellière et al., 2020; Pilling, 2009). On balance, these data indicate that there is typically an attenuation of the ERP components associated with speech processing under condition of A/V versus A-only presentations. Developmental changes in these effects have also been reported, with younger children showing less influence of visual speech cues on auditory ERP components compared to older children (Knowland et al., 2014). We investigate the contributions of A/V speech processing in congenitally deaf children who have received a cochlear implant (CI). We have collected data from deaf children with CI (n = 30; mean age = 81 mos; mean age of CI activation = 27 mos, n bilaterally implanted = 23) and typical hearing children (n = 19; mean age = 75 mos) in a word-picture priming paradigm in which audio-visual presented word primes preceded picture targets. In the current work we explore the effects of processing of the spoken Audio-Visual primes in this data set. Results demonstrate more positive P1 and P2 responses for CI-using children compared to hearing controls ($p = .017$ and $p = .043$, respectively), but no differences in N400 responses ($p = .142$). We also explore age-related differences in these responses, motivated by findings that suggest that visual P1 responsivity may increase with age ($R = 0.286$, $p = .004$) in both populations. Moreover, attentional P2 latency was found to decrease with age in the control group ($R = -0.199$, $p = .014$), but not in the CI group ($R = -0.07$, $p = .278$). For the CI group, age at CI activation was negatively correlated with attentional P2 amplitude ($R = -0.27$, $p < .001$); CI users' time-in-sound was positively correlated with P2 amplitude ($R = 0.18$, $p = .005$). Thus, more experience with CI was associated with greater attentional response to A/V speech. In light of this, we conclude that audiovisual speech may evoke greater visual reactivity and require more attention from CI children than controls; further, as typical hearing children age, they can process A/V speech more quickly as reflected by shorter P2 latencies. These differences in early sensory and attentional processing, however, lead to comparable comprehension and semantic processing between groups as evidenced by similar N400 responses. These data will help inform our understanding of attentional and perceptual speech processing in children with cochlear implants.

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1318: LANGUAGE AND AUDITORY SKILLS OF CHILDREN WITH SINGLE-SIDED DEAFNESS AND A COCHLEAR IMPLANT

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Single-sided deafness (SSD), i.e. profound hearing loss in one ear (> 90 dB HL) and normal hearing in the other ear, affects approximately 20 newborns each year in Flanders (Belgium). These children have no access to binaural hearing, making it difficult to localize sounds or understand speech in noisy environments. The single-sided auditory deprivation can affect the children's brain development, resulting in asymmetric auditory processing and the disruption of higher-order brain connectivity. Finally, SSD is a risk factor for speech-language delays and academic underachievement. Despite these consequences, there is currently no standard care for children with SSD in Belgium (as is the case for many other countries worldwide). A cochlear implant (CI) is the only treatment option that can restore bilateral hearing and may even enable binaural hearing. Given the sensitive period for brain development early in life, early implantation is important to achieve optimal outcomes.

In our current multicenter study (Leuven, Antwerp, Ghent), fifteen infants with prelingual SSD received a CI at a very young age (range 8-26 months, mean 13.6 ± 4.8 months). At regular intervals, we document the children's development with regard to language, cognition, and spatial hearing skills. We expected that the CI would promote normal language and cognitive development and improved spatial hearing outcomes in these children. While the study is still ongoing, we have collected enough data to see some significant trends emerging.

At the conference, we will present the most recent data of the implanted children, ranging to up to 6 years post-implantation. We compare their data to those of normal-hearing peers and those of children with untreated single-sided deafness. In particular, we will focus on expressive language skills (vocabulary and grammar), spatial speech perception in noise, and sound localization abilities.

1360: THE PERCEPTION OF VOICE GENDER CUES AND THE BENEFIT FROM VOICE DIFFERENCES IN PERCEPTION OF SPEECH IN COMPETING SPEECH IN PRELINGUALLY DEAF CHILDREN WITH COCHLEAR IMPLANTS

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Voice characteristics support speech perception in competing speech by helping listeners to distinguish target from masker speech. Although voice cues are still present to some extent in electrical stimulation, postlingually deaf CI adults have difficulties with voice discrimination, as well as benefitting from voice differences in concurrent speech perception. However, it is not yet known how voice perception by prelingually deaf children with CIs develops. Unlike postlingually deaf CI adults, the onset of deafness is during the period of language development, and their auditory system develops primarily based on spectrotemporally degraded speech input. CI children may be able to harness their high brain plasticity to learn to exploit the residual voice cues present in electrical stimulation. Hence, the voice perception abilities of CI children may develop as a function of age, like those of normal-hearing (NH) children during the school-age years. Alternatively, their abilities may plateau at a certain age due to sensory limitations and the lack of exposure to a normal acoustic speech signal.

In this study, we examined the development of voice cue perception, specifically, average fundamental frequency (F0) and vocal-tract length (VTL), the primary acoustic cues related to voice gender. We examined NH and CI children's ability to discriminate differences in F0 and VTL (Experiment 1), the perceptual weight they attributed to F0 and VTL cues for voice gender categorization (Experiment 2), and their benefit from target-masker voice differences in F0 and VTL for speech perception in competing speech (Experiment 3). Additionally, we examined how these different voice perception abilities, which varied from lower-order perception to higher-order cognitive tasks, developed with age and how these were related to each other.

Our results show that the F0 and VTL discrimination thresholds of CI children were generally higher (worse) than those of their NH age peers, although some CI children had thresholds within the normal range. Their thresholds improved with age and were better, on average, than those of CI adults reported by previous research. For voice gender categorization, the perceptual weight attributed to F0 and VTL cues did not differ between NH and CI children, unlike the adults, where previous research had sown CI adults had differing weights than NH adults. Finally, concurrent speech perception was overall more difficult for CI children compared to their NH age peers, but they benefitted to a similar degree from target-masker voice differences in F0 and VTL, unlike the CI adults, who showed no or minimal such benefit, as was reported previously. Thus, although CI children's F0 and VTL discrimination abilities are generally poorer than those of their NH age peers, their weighting of F0 and VTL cues for voice gender categorization and their benefit from target-masker differences in F0 and VTL were similar to NH children. Our results also imply that high brain plasticity in CI children results in more effective use of the voice cues that are available in the spectrotemporally degraded CI signal compared to CI adults. Together, these results indicate that, unlike CI adults, CI children learn to use the residual F0 and VTL cues present in the CI electrical stimulation for voice gender categorization and to better perceive speech in competing speech.

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1371: EVALUATING THE FUNCTIONAL AUDITORY SKILLS OF CHILDREN WITH BILATERAL CIS AND BIMODAL FITTING

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Aim: The study aims to compare the auditory skills of children fitted with bilateral cochlear implants (CIs), bimodal setting (CI and a contra-lateral hearing aid), and children with normal hearing.

Method: The participants included 55 children who were bilaterally implanted (BIL), 63 children with bimodal fitting (BIM), and 59 normal hearing (NH) children. All the children with hearing loss have been enrolled in auditory-verbal intervention services provided by Children's Hearing Foundation in Taiwan. In addition, each group was further divided into two age groups, which were younger group (0-48 mo.) and older group (49 to 78 mo.). The evaluation tool was the Mandarin version of Auditory Skills Checklist-Short Form (ASC-SF), originally developed by Meinzen-Derr et al. (2007). Mandarin ASC-SF consists of 19 items, which can be divided into four sub-scales, according to the auditory skill developmental stages defined by Erber (1982): detection, discrimination, identification, and comprehension. A rating of 0, 1, or 2 was assigned to each item, by the child's auditory-verbal therapist, which represents the child not having the skill, developing the skill, or consistently demonstrating the skill, respectively.

Results:
Two-way ANOVAs showed significant main effects of fitting type (BIL, BIM, NH) for discrimination ($F=5.14$, $p=.007$), identification ($F=8.43$, $p<0.001$), comprehension ($F=7.73$, $p=.001$) and total score ($F=8.25$, $p<0.001$). Post-hoc comparisons revealed that: (1) BIM group showed lower skills than NH group in terms of discrimination ($p=.005$), identification ($p<0.001$), comprehension ($p<0.001$), and total score ($p<0.001$); (2) BIL group performed worse than NH group only for the comprehension sub-scale ($p=.04$). Significant main effects of age were also observed for comprehension ($F=7.97$, $p=.005$) and total score ($F=5.99$, $p=.015$), where scores of older children (49-78 mo.) were significantly higher than those of younger children (0-48 mo.). This may imply that auditory-verbal therapy supports children with CI(s) to develop fundamental auditory skills (detection, discrimination, and identification in early years. However, for CI children younger than 4 years of age, the more advanced skills (comprehension) are still emerging. In addition, significant interaction was observed only for the comprehension sub-scale ($F=3.76$, $p=.025$). Post-hoc comparisons revealed no significant differences among the fitting types for younger children (0-48 mo.). However, for older children (49 to 78 mo.), NH group performed significantly better than the BIM and BIL group for the comprehension sub-scale ($p<0.0001$). It is worth noted that no significant differences were observed between the BIM and the BIL group for the comprehension sub-scale, either in the younger or older group (younger group: $p=.35$; older group: $p=.21$).

Conclusion:
While children with bimodal fitting seemed to performed the worst in terms of auditory skills, statistics did not show significant differences in ASC scores between the bimodal and bilateral group for all the sub-scales and the total score, either for the young or the older group. These results indicate that there may be no so-called "the best choice fitting" for all. Clinically, professionals should provide intervention recommendations based on individualized hearing needs, including (but not limited to) the child's unaided and aided thresholds, as well as the performance in speech audiometry.

1492: CHILDREN WITH SLOPING HEARING LOSSES HAVE BETTER SUPRATHRESHOLD AUDITORY ABILITIES THAN ADULTS WITH SIMILAR PATTERNS OF LOSS

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Background: There is considerable appeal to the idea of preserving and using low-frequency acoustic hearing in combination with electric hearing (EAS) to provide important cues for listening in noise, localization of sound and enhanced quality of sound. However, the benefit of EAS over electric-only stimulation is highly variable and difficult to predict from an audiogram. It would be clinically useful to be able to assess for residual hearing patients not just their ability to detect sounds but to process them. In a recent study (Spitzer et al., 2021), we measured performance on a spectral-temporal test (SMRT) with acoustic hearing with a steeply sloping audiograms in adults typical of EAS candidates. Performance on the test (avg. 1.6 RPO) was much lower than that of normal hearing controls using a low-pass filtered version of the test to simulate a typical sloping audiogram (avg. 5.5 RPO). Given the similar audibility for the two populations, the differences in SMRT scores are considered an index of how well the residual hearing is able to process suprathreshold auditory information (i.e. the “quality” of the residual hearing), which influences speech perception in addition to other auditory abilities.Children with hearing loss may have similar audiograms to post-lingually hearing impaired listeners. However, the etiologies and disease progression of the hearing loss of children is different than for those who begin to lose their hearing as adults. In the present experiment, we are adapting our previous work with adults to a pediatric population. The primary motivation for this project is to determine if for a given audiometric profile, children and adults would be expected to have similar ability to process suprathreshold auditory information.

Methods: Children with steeply sloping audiograms (hearing aid users) and age-matched NH children participated in this study. Spectral-temporal resolution was measured with the spectral-temporal modulated ripple test (SMRT), and speech perception was measured with age-appropriate materials. Listeners with NH listened to stimuli through low-pass filters and at two levels (40 and 60 dBA) to simulate low and high audibility. Listeners with hearing loss listened to SMRT stimuli unaided at their most comfortable listening level and speech stimuli at 60 dBA. The protocol is similar to our earlier work (Spitzer et al., 2021) but differs in the population tested.

Results: For pilot data, children appear to perform better than adults with similar hearing loss on SMRT (avg. 3.4 RPO), though still below listeners with NH, suggesting performance is not completely attributable to audibility. There appear to be relationships between age, SMRT score, and mid-frequency audiometric thresholds.

Conclusions: NH simulations describe a “best case scenario” for hearing loss where audibility is the only deficit. For adult listeners with hearing loss, the likely broadening of auditory filters, loss of cochlear nonlinearities, and possible cochlear dead regions may have contributed to distorted spectral resolution and thus deviations from the NH simulations. Comparatively, children perform better than adults with similar hearing losses, suggesting that the disease process between the groups is different, involves the apical portion of the cochlea to a different extent and therefore is less detrimental to auditory processing abilities. This suggests preserving low frequency hearing in children may be more beneficial than in adults. Still, this hearing may be lost over time as dictated by the underlying etiology of the hearing loss in these children.

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1509: CONSONANT PERCEPTION-PRODUCTION ERROR PATTERNS IN NORMAL HEARING CHILDREN AND PEDIATRIC COCHLEAR IMPLANT USERS

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Introduction: Speech perception and production skills in children using cochlear implants (CIs) are associated with a wide range of scores. Production performance may exceed perception in children using CIs (Kishon-Rabin et al., 2002), while the reverse is generally seen in normal hearing (NH) children. The purpose of this study is to analyze perception and production error patterns in NH and CI groups of children to provide avenues for developing rehabilitation approaches for children using CIs. Results of this study indicated that production exceeded perception in pediatric CI users but not in NH children and different patterns of errors were observed between the groups. Overall, perception and production errors did not mirror one another.

Methods: Two groups of children participated in this study. The implant group included 20 children from 5 to 9 years of age who were implanted before age of three and the control group comprising 20 NH hearing age-matched children from 4 to 7 years of age.Speech perception and production skills were evaluated using a modified version of the California Consonant Test (CCT) (Owens & Schubert, 1977) and included 12 consonants (/f/, /v/, / θ/, /s/, /z/, /ʃ/, /p/, /b/, /t/, /d/, /k/, and /g/). Consonants were presented in consonant – vowel – consonant (CVC) words in initial and final positions. Speech perception was evaluated by presenting a set of four different pictures on a computer screen. Each picture expanded in size over the course of .5 sec during the playback of the audio signal represented by the picture. On each trial, participants heard the CVC word presented in a carrier sentence, “Show me ____” and the participant selected the corresponding picture on the computer screen. Speech production was evaluated by presenting the target picture on the screen. Participants heard the instruction “Say the word ____” when the picture corresponding to the target word appeared on the screen. Participants’ responses were recorded for later transcription by three speech-language pathologists. Transcription reliability between transcribers was 80% or higher for 20% of the stimuli. The stimuli were presented at 65dB SPL in a sound booth.

Results: Production exceeded perception in the CI group but not in the NH group. The error patterns for individual consonants in these groups were different. For example, the most common substitution in the CI and NH groups for perception was the consonant /v/, but children from the CI group most often substituted it with /z/ but children with NH substituted it with /f/. For production, the most common error was the consonant /θ/, and both groups substituted it with /f/. Group differences were found when analyzing specific consonant features, indicating some performance differences. For example, the NH group perceived stop consonants significantly better (fewer errors) than the CI group. The NH group produced voiced consonants significantly worse than voiceless consonants. Perception and production errors generally did not mirror one another. For both groups, the error patterns that were evident for perception were not necessarily evident for production performance.

Conclusions: The data from this study support the need for further evaluation of mechanisms underlying the perception and production error patterns in children using CIs. Perception and production error patterns for individual consonants were different and perception errors did not mirror the production errors. These error patterns suggest that therapy for CI participants needs to take into account both perception and production abilities.

Psychophysics – Featured Talk + Posters

Featured Recorded Talk:

1341: ESTIMATING HEALTH OF THE IMPLANTED COCHLEA USING PSYCHOPHYSICAL STRENGTH-DURATION FUNCTIONS AND ELECTRODE CONFIGURATION

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It is generally believed that the efficacy of cochlear implants (CIs) is partly dependent on the condition of the stimulated neural population. Cochlear pathology is likely to affect the manner in which neurons respond to electrical stimulation, potentially resulting in differences in perception of electrical stimuli across CI recipients and across the electrode array in individual CI users. Several psychophysical and electrophysiological measures have been shown to predict cochlear health in animals and have been used to assess conditions near individual stimulation sites in humans. In this study, we examined the relationship between psychophysical strength-duration functions and spiral ganglion neuron density in two groups of cochlear-implanted guinea pigs that had minimally-overlapping cochlear health profiles. One group was implanted in a hearing ear (IH group; N = 10) and the other group was deafened by cochlear perfusion of neomycin, inoculated with an adeno-associated viral vector with an Ntf3-gene insert (AAV.Ntf3) and implanted (NNI group; N = 14). Psychophysically measured strength-duration functions for both monopolar and tripolar electrode configurations were then compared for the two treatment groups. Results were also compared to histological outcomes.

Overall, there were considerable differences between the two treatment groups in terms of their psychophysical performance as well as the relation between their functional performance and their histological data; these differences were mor pronounced using tripolar configuration.

Animals in the NNI group exhibited steeper strength-duration function slopes than those in the IH group. Slopes were positively correlated with spiral ganglion neuron density in the NNI group (steeper slopes in animals that had higher spiral ganglion neuron densities) but not in the IH group. Across all animals, slopes were negatively correlated with ensemble spontaneous activity levels (shallower slopes with higher ensemble spontaneous activity levels). We hypothesize that differences in strength-duration function slopes between the two treatment groups were related to the condition of the inner hair cells, which generate spontaneous activity that could affect the across-fiber synchrony, and/or the size of the population of neural elements responding to electrical stimulation. In addition, it is likely that spiral ganglion neuron peripheral processes were present in the IH group, which could affect membrane properties of the stimulated neurons. In summary, results suggest that the two treatment groups exhibited distinct patterns of variation in conditions near the stimulating electrodes that altered the effects of phase duration and electrode configuration on detection thresholds. These results suggest that psychophysical strength-duration functions can serve as a predictive measure of cochlear health in CI recipients.

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1319: SENSITIVITY TO PULSE PHASE DURATION AS A MARKER OF NEURAL HEALTH ACROSS COCHLEAR IMPLANT RECIPIENTS AND ELECTRODES

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In cochlear implants (CIs), loudness has been shown to grow more slowly with increasing pulse phase duration (PPD) than with pulse amplitude (PA), possibly due to “leaky” charge integration. We recently quantified this leakiness in terms of “charge integration efficiency” (CIE), defined as the log difference between the PPD dynamic range (DR) and PA DR (both expressed in charge units), relative to a common threshold anchor. Such leakiness may differ across electrodes and/or test ears, and may reflect underlying neural health.

In this study, we examined the across-site variation of charge integration in recipients of Cochlear© CI devices. PPD and PA DRs were measured relative to a common threshold anchor. The stimulation rate was 1000 pulses/second and the stimulation mode was MP1+2. To estimate the PA DR, the PPD was fixed (25 or 50 microseconds), the PA was increased until achieving threshold and then further increased until achieving maximum acceptable loudness (MAL). The PA threshold was then used as the fixed amplitude with which to measure the PPD DR. The PPD threshold was fixed (25 or 50 microseconds), and the PPD was increased until achieving MAL. Thus, the PA and PPD DRs were estimated relative to a common threshold anchor. DRs were converted to charge units (nano-Coulombs, or nC), and CIE was calculated for each available electrode. Strength-duration functions, as measured in previous studies, were compared to CIE on selected electrodes.

Results showed no significant or systematic relationship between the across-site variation in CIE and electrode position or threshold levels. Charge integration efficiency was poorer with the 50-microsecond threshold anchor than with the 25-microsecond anchor, suggesting that greater leakiness was associated with larger PPD DRs. Poorer and more variable CIE across electrodes was associated with longer duration of hearing loss, consistent with the idea that poor integration is related to neural degeneration. More variable CIE was also associated with poorer speech recognition performance across test ears. The slopes of the strength-duration functions at MAL were significantly correlated with CIE. However, the strength-duration slopes were not significantly correlated with duration of hearing loss or speech performance. As such, CIE may be a better candidate to measure leakiness in neural populations across the electrode array, as well as the general health of the auditory nerve in human CI recipients.

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1333: A WEB-BASED IMPLEMENTATION OF THE STRIPES SPECTRO-TEMPORAL TEST

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The continuing global pandemic has highlighted the need for web-based diagnostic tools for cochlear-implant (CI) listener testing. The STRIPES (Spectro-Temporal Ripple for Investigating Processor Effectiveness) spectro-temporal test has been shown previously to be sensitive to CI-processing manipulations and correlate with speech intelligibility. It is also robust to changes in presentation method (e.g. loudspeakers). Therefore, the test is a strong candidate for deployment as a web-based diagnostic tool (webSTRIPES).

The STRIPES 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 across-channel perception of the stripe direction, not cues from a single channel or amplitude modulations. The task difficulty is varied by changing 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 differentiate. WebSTRIPES was written in JavaScript, using the JsPsych library, and hosted on a JATOS server. The test was presented to CI listeners through a web-browser accessed via internet-enabled devices (e.g. smartphone, tablet, laptop), and sound was presented via a Bluetooth connection to any proprietary device listeners used to connect Bluetooth-enabled devices to their CIs (e.g. Phonak ComPilot for Advanced Bionics users).

An analysis of all published STRIPES data to date revealed that the number of reversals used in each staircase could be reduced from 12 to 8 without significantly changing the thresholds obtained. This change reduced the average number of trials presented in each staircase from 57 to 42. As the later trials are shorter in duration than the earlier trials, a 25% reduction in the number of trials resulted in a 15-20% reduction in the overall duration of each staircase. This reduction in reversals was implemented in webSTRIPES.

12 CI listeners who have taken part in previous STRIPES studies (Archer-Boyd et al., 2020) have been recruited. Their results using webSTRIPES will be presented and compared to the thresholds obtained using the previous loudspeaker presentation method. Further data collection is ongoing that includes testing webSTRIPES using other manufacturer’s devices, and a large-scale study of the correlation between STRIPES thresholds and speech intelligibility.

1337: PITCH PERCEPTION IMPROVES WITH INCREASING MODULATION DEPTH IN NORMAL HEARING AND COCHLEAR IMPLANT USERS

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Pitch has been aptly defined as the perceptual correlate of the periodicity of sounds. The fundamental frequency of voiced speech and of musical notes produces a complex pattern of spatial and temporal variations across the auditory nerve. Cochlear implants (CIs) attempt to mirror this process by delivering temporally modulated pulse trains to electrodes along the length of the auditory nerve. Cochlear implants allow for sub-microsecond control over the temporal properties of stimulation. Despite this exceptional control, pitch perception provided by CI stimulation is significantly worse than that of normal-hearing listeners even when normal-hearing listeners are limited to temporal cues associated with spatially unresolved harmonics. This study examines the extent that resolution on a pitch-ranking task depends on modulation depth of the temporal cues. Two experiments will be described. In the first experiment, adults with normal hearing and adults who use cochlear implants were tested on pitch ranking of modulated sounds —pure tones and bandpass-filtered white-noise— with modulation depth systematically controlled. Carrier rate for pure tones and center frequency for the filtered noise was centered at either 4 or 6kHz for CI users and normal hearing, respectively. Sinusoidal amplitude modulation was then applied for modulation frequency conditions of 110, 220, and 440 Hz. Modulation depth was systematically varied with conditions including 25, 50, 100, 200, and 400% modulation depth with 200% depth corresponding to half-wave rectification (i.e., “transposed”) and the 400% condition further temporally sharpened. Results indicate that pitch ranking is better when provided by stimuli with deeper temporal modulations for both normal hearing and CI users. The second experiment examines similar stimuli but bypassing clinical sound processing to directly test the extent modulation depth affects pitch ranking in CI users when presented amplitude-modulated pulse trains on a single electrode. Preliminary results from the second experiment further supports that pitch ranking is better provided by stimulation with deep modulations. We interpret these results as evidence that modulation enhancement can improve pitch perception for cochlear implant users.

1343: PLACE-PITCH DISCRIMINATION OVER THE FULL ELECTRODE ARRAY

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Objective: To investigate variations in place-pitch discrimination along the electrode array and to validate an improved version of our earlier published full-array pitch discrimination test (Biesheuvel et al. 2019).

Study sample: Twenty-five adults implanted with an Advanced Bionics CI (mainly HiRes90K MS) with at least 6 months of CI experience.

Design: Subjects performed two different three-alternative forced choice (3AFC) psychophysical experiments on place-pitch discrimination. In both experiments, subjects had to identify one stimulus (probe) as being the odd-one-out, compared to two reference stimuli. The reference stimuli were stimulated at the physical contact of interest and probe stimuli were created using simultaneous dual electrode stimulation (DES, also called current steering). In the first experiment, three pre-defined channels were measured, as determined on multi-slice computed tomography, located at: 120° (basal), 240° (middle) and 360° (apical) from the round window. On these three channels, pre-defined inter-channel distances (ICDs) ranging from 2 (physical electrode contact distances) to 0.1 (DES, α=0.1) were tested, with 12 trials each. Psychometric functions (PF) were fitted with MATLAB leading to the Just Noticeable Difference (JNDα, 66%-threshold). Secondly, subjects completed a pitch-discrimination task on every channel of the electrode-array. In our earlier published design, three discrete ICDs were used (1, 0.5 and 0.25; Biesheuvel et al. 2019). In the new test, probe-stimuli could take values between ICDs 2 and 0.25 with stepsize 0.25. After five repetitions on the 'easiest' probe condition (ICD = 2), the score was evaluated (against 80% correct) to adaptively increase or decrease the ICD for the next round. The test stopped after testing 4 different ICDs and provides a discrimination score Dα (lowest ICD where 80% correct is met) for all tested channels. For comparison with speech perception scores, we used free-field consonant-vowel-consonant phoneme recognition scores as measured during the subjects' regular clinical program.

Results: Twenty-four subjects completed PFs for all three tested regions, one subject completed only middle and apical PFs. Average JNDα was 0.65; there was no significant difference between JNDα per region. Between subjects, JNDα and Dα scores varied widely. Contrary to our earlier work, Dα was distinguished on almost all tested channels. Both tests took approximately equally long to complete (±45 minutes). Linear correlations showed a significant relationship between JNDα and speech perception score in quiet (65dB and 75dB SPL) and in speech shaped noise (65dB SPL, +10dB SNR). For comparison with the second algorithm, JNDα scores were grouped by Dα scores 0.25, 0.5, 1 and >1. All groups were significantly different from one-another. The mean JNDα scores show a significant linear correlation with the mean Dα scores ($p<.0001$; adjusted $R^2 = 0.58$).

Conclusions: The significant relationship between PF threshold and speech reception score show that pitch discrimination ability could be a useful parameter in clinical fitting. The full-array test in its current form can be completed with minor supervision and distinguishes between pitch discrimination performance on the full array, in approximately the same time it took to measure three (more accurate) PFs (±45 minutes). Further analysis has to show whether this test can be used to accurately determine regions of lesser pitch discrimination performance which could be useful in clinical fitting.

References

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1358: RECONCILING MEASURES OF SPEECH PERCEPTION WITH SPECTRAL AND INTENSITY RESOLUTION IN VOCODER SIMULATIONS OF COCHLEAR-IMPLANT PERCEPTION

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Perception via a cochlear implant (CI) is often simulated in normal-hearing (NH) listeners via noise- or tone-excited envelope vocoders that approximate the poorer spectral resolution of CIs by a combining a limited number of spectral channels with simulated current spread. Previous work comparing spectral resolution and speech perception in NH listeners and CI recipients has found that the reduction in spectral resolution of a vocoder needed to match performance on a speech-in-noise task resulted in poorer performance in NH listeners than CI recipients on tasks involving spectral ripple detection and discrimination. The aim of the current work is to devise a vocoder that provides as comprehensive simulation of CI performance as possible. Spectral ripple detection and discrimination performance is likely limited by both spectral and intensity resolution, but most previous vocoder simulations have focused solely on spectral resolution. Here we evaluated a vocoder processing strategy simulating electric field spread, dynamic range limitations, and frequency-to-place mismatch with NH listeners using speech-in-noise (IEEE sentences) and spectral-resolution tasks (STRIPEs, spectral ripple detection and discrimination) to compare with data obtained from CI recipients. Data were collected online using a remote testing platform implemented using the MATLAB Web App Server. In-lab data were used to validate online findings for a subset of tasks. A comparison between groups shows that combining limitations on spectral resolution with reduced intensity resolution can produce a better match between NH and CI group-level performance, using the same vocoder parameters for all tasks. The results demonstrate that including simulations of multiple aspects of the information degradation that occurs in cochlear implants can achieve better generalizability of vocoder results to the CI population.

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1372: A CLINICALLY FEASIBLE METHOD TO IDENTIFY NEURAL DEAD REGIONS IN ADULT COCHLEAR IMPLANT USERS

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One factor that has been hypothesized to contribute to the variability in cochlear implant (CI) outcomes is the density of spiral ganglion cells (SGCs) in the peripheral auditory system. However, temporal bone studies have not shown a strong relationship between the number of surviving SGCs and speech understanding scores. Instead, evidence is now mounting to support the hypothesis that the variation in neural survival along the cochlea has a strong influence on speech understanding.

In this study, a new method of identifying neural dead regions in CI users – an electrode(s) at a site that preferentially activates neurons that are located at other locations instead of any surviving neurons at the position in question – is evaluated by comparing hearing thresholds using focused electrical stimulation (bipolar mode) and broad electrical stimulation (monopolar mode). Because both stimulation modes are equally affected by electrode-to-modiolar distance, while focused stimulation is more sensitive to local SGC density specifically, comparing thresholds using both stimulation modes will separate the effects of electrode-to-modiolar distance and SGC density on hearing thresholds. We hypothesized that off-frequency listening (hence neural dead regions) will occur in places where the SGC density is very low compared to nearby areas, and this situation will be characterised by a large increase in threshold difference compared to surrounding areas.

Hearing thresholds were obtained on single electrodes via direct stimulation of the electrode array using bipolar and monopolar stimulation mode. Psychophysical spatial forward masking functions were then measured in regions near where the difference between monopolar and bipolar thresholds was changing rapidly to evaluate if off-frequency listening was occurring, suggesting a neural dead region. Preliminary data in three adult Nucleus CI users showed elevated and highly variable bipolar thresholds compared to monopolar thresholds. Off-frequency listening, identified by a shift in the peak of the forward masking pattern, was found in one out of the three participants.

These preliminary results suggest that the electrode locations showing the greatest difference between bipolar and monopolar hearing thresholds and/or where rapid thresholds changes occurred may be indicative of a neural dead region. Other attributes of the hearing threshold profile, in addition to the difference in threshold level for both stimulation modes, will be evaluated for their use in accurate identification of dead regions. In this way, rules of thumb can be formulated just from the results of the hearing threshold testing alone, which offers a clinically feasible method, rather than psychophysical experimental tasks. Speech understanding will also be tested to further evaluate the relationship between neural dead regions and speech understanding performance in CI users.

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1395: IMPACT OF PROCESSING-LATENCY INDUCED INTERAURAL DELAY ON ILD SENSITIVITY IN CI USERS

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Introduction:
Bimodal cochlear implant (CI) users with contralateral hearing aid can perceive binaural cues and are able to localize sounds, but less precisely than bilateral CI users or CI subjects with single-sided deafness and contralateral normal hearing (SSD-CI). It was recently shown that compensation of interaural delay induced by processing latencies (e.g. differences in processing latencies between hearing aid and CI) could improve sound localization. Since sensitivity to interaural time differences (ITDs) is rather poor in CI users (especially for fine-structure ITDs), it is still unclear whether this improvement is induced by better ITD representation or by a more correct temporal integration to calculate interaural level differences (ILDs). The aim of the study was to measure sensitivity to ILDs in SSD-CI and normal-hearing subjects for different interaural delays outside of the physiological ITD range.

Method:
9 SSD-CI users (all with MED-EL implants and sound processors) and 26 normal-hearing (NH) subjects participated in this study. The just noticeable difference (JND) of ILDs for broadband noise (duration: 500 ms, bandwidth: 0.1-15 kHz) was measured using a 2-AFC procedure. Stimuli were presented binaurally via headphones (SSD-CI group: CI stimulation via direct cable connection). The JND-ILDs were measured for different interaural latencies between 0 and 15 ms. The test procedure was conducted for ILD references of 0 dB and 10 dB (i.e. lateralized sound).

Results:
For a reference ILD of 0 dB, mean JND-ILDs in the NH group ranged between 1.4 dB (no delay) and 3.9 dB (15 ms delay). There was a significant effect of interaural delay. JND-ILDs in the SSD-CI group ranged between 4.5 dB (no delay) and 7.8 dB (10 ms delay) and were significantly higher than in the NH group. Due to the high individual variation in JND-ILDs no significant effect of interaural delay was found. The NH group showed significantly worse sensitivity to ILDs for a reference ILD of 10 dB, which could not be shown in the SSD-CI group.

Discussion:
In NH subjects, interaural delay significantly reduced ILD sensitivity. A tendency of reduced ILD sensitivity with increasing delay was also found in the SSD-CI group. This supports the hypothesis that decreased localization performance in CI users induced by an interaural processing delay is due to both reduced ITD and ILD sensitivity.

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1404: ASYMMETRY IN DURATION PERCEPTION REVEALED BY COCHLEAR-IMPLANT ELECTRICAL CHIRPS

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In normal hearing, the filtering imposed by the cochlea produces frequency-dependent delays. In response to a broadband click, auditory nerve (AN) fibers coding for low frequencies discharge later in time than AN fibers coding for higher frequencies. This delay amounts to about 10 ms considering frequencies between 100 Hz and 10 kHz. This implies that the peripheral neural representation of a sound does not match its physical duration. Dau et al. (2000) designed a chirp rising in frequency that yielded more synchrony across the auditory nerve array as demonstrated by larger auditory brainstem responses than those obtained with a click. Nevertheless, such an optimized chirp is still perceived as longer in duration than a click. Uppekamp et al. (2001)proposed two possible explanations for that: (i) First, it could be due to within-channel duration cues because basilar membrane ringing lasts longer for the optimized chirp than for a click despite the higher across-channel synchrony; (ii) Second, it is possible that there is a more central mechanism in the auditory system that compensates for the cochlear delay. Here, we test this second hypothesis with cochlear implant (CI) listeners as they provide a direct access to the auditory nerve and avoids the confounding effect of differences in within-channel duration.

Eight CI users of the Med-EL device took part in a series of psychophysical and electrophysiological experiments. In Experiment 1, they were asked to compare the perceived duration of 12 different electrical chirp stimuli spanning the entire electrode array and differing in their overall duration (from 1.3 to 40 ms) and/or in their direction (base-to-apex and apex-to-base). The stimuli were loudness-balanced sequences of pulses with a very short (2-µs) inter-pulse interval and used current steering to span the electrode array at different speeds. The duration ranking experiment used the midpoint comparison procedure consisting of repeated series of two-alternative forced choice trials, yielding for each stimulus a mean rank and associated standard deviation. The results showed a significant interaction between overall duration and chirp direction. At long durations (10 ms and more), the chirp roughly mimicking the physiological cochlear delay (base-to-apex) was perceived as shorter than its time-reversed version.

To ensure that this difference was not due to a particularly strong masking produced by the basal electrodes on the apical fibers in the case of the base-to-apex chirp, Experiment 2 used an odd-man-out task where subjects had to discriminate between a 20-ms chirp and the same chirp with either the beginning or the end removed. Despite a large subject variability in the patterns of results, there was no trend for a stronger masking produced by the base-to-apex than by the apex-to-base chirp.

These two experiments strongly suggest the existence of a central auditory mechanism compensating the natural cochlear delay.

1410: THE PERCEPTION OF RAMPED PULSE SHAPES IN COCHLEAR IMPLANT USERS

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The electric stimulation provided by current cochlear implants (CI) is not very power efficient. One underlying problem is the poor efficiency by which information from electric pulses is transmitted into auditory nerve fibers. A novel stimulation paradigm using ramped pulse shapes has recently been proposed to reduce this inefficiency. The primary objective is to achieve a better biophysical replication of spiral ganglion neuron activation using ramped pulses instead of the rectangular pulses used in most CIs today.

In the current study, we tested the hypotheses that ramped pulses provide more efficient stimulation than rectangular pulses and that a rising ramp is more efficient than a declining ramp. Rectangular, rising ramped and declining ramped pulse shapes were compared on charge-efficiency, discriminability, and threshold variability in seven listeners with Advanced Bionics devices. Each pulse had a duration of 97 µs/phase, no interphase gap, and anodic-first polarity. Ramped pulses had a pedestal at 50% of the threshold level of the rectangular pulse and were increased (rising ramp) or decreased (declining ramp) linearly across the entire phase duration. Using each of these pulse shapes, threshold detection, loudness-balancing, discrimination, and threshold profiling were measured.

Results indicated that reduced charge, but increased peak current amplitude, were required at threshold and most comfortable levels with ramped pulses relative to rectangular pulses. One subject could reliably discriminate between equally loud ramped and rectangular pulses on the group level, suggesting variations in neural activation patterns between pulse shapes in that participant. No significant difference was found between rising and declining ramped pulses in any of the tests.

In summary, our findings show the benefits of charge-efficiency with ramped pulses relative to rectangular pulses and they indicate that the direction of a ramped slope is of less importance. For most of the participants, no perceptual difference between pulse shapes was observed.

1429: LOUDNESS SUMMATION OF INTERLEAVED PULSES: EFFECTS OF TEMPORAL AND SPATIAL SEPARATION AND RELATION TO NEURAL INTERACTION

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Loudness summation refers to the situation in which the loudness of different sounds presented together is greater than their individual loudness. In acoustic hearing, loudness summation differs for tones that are separated by more than a critical band from those that interact at the basilar membrane. We hypothesize that loudness summation of cochlear implant current pulses depends on their temporal and spatial separation, and the effects of varying temporal and spatial separation on loudness can be explained by interactions at the electrode-neural interface. This hypothesis was tested by evaluating loudness summation for pairs of interleaved pulses at various temporal and spatial distances, and measuring their interactions at the neural level by using electrically-evoked compound actions potentials (ECAP) recorded from the implant device.

The first experiment evaluated psychophysical loudness summation using a similar method to McKay and McDermott (1998), in which pulse train stimuli with either a single pulse or a pair of pulses per each 50ms period were loudness balanced. We measured the increase in the current of the single-pulsed stimulus that was required to achieve equal loudness to the paired-pulse stimulus. Two parameters were varied in the paired-pulse stimuli. First, electrode separation was varied by changing the cochlear location of the first pulse, while fixing the second pulse on an electrode in the middle of the array. Secondly, we used different time delays between the two pulses (ranging from 0.25 to 20 ms), to evaluate temporal effects on loudness.

The second experiment evaluated neural interaction between individual pulses of the same pulse pairs of the previous experiment. ECAP was measured for the second pulse when it was preceded by the first pulse as well as presented in isolation. The difference between the two ECAP measures indicates neural effects due to the first pulse such as refractoriness and facilitation, and is used to quantify interaction between the two pulses as a function of temporal and spatial separation.

Preliminary results of experiment 1 confirm that loudness evoked by a pair of pulses is affected by their temporal and spatial separation. ECAP accounted for some of the effects of spatial and temporal distance on loudness summation, but only when the time delay between the two pulses was less than the ECAP refractory period (typically ~4ms). Results so far suggest that loudness summation is related to ECAP, and has the potential to be used as a probe for peripheral neural effects in cochlear implant users.

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1442: COMPARING ONLINE AND IN-LABORATORY IMPLEMENTATIONS OF THE QUICK SPECTRAL MODULATION DETECTION TEST FOR COCHLEAR IMPLANT USERS

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Accelerated by the Covid-19 pandemic, there is a new emphasis on collecting data remotely for both clinical and research use. The development of online tests is relatively straight-forward. A greater challenge is to be able to collect data remotely that is equivalent to data that would have been collected in the laboratory or clinic. One limitation is that remote testing typically involves uncontrolled or uncalibrated acoustic presentation. Another limitation is the lack of an audiologist providing instructions, guidance, and ensuring the process goes smoothly. As such, the usability of the test and interface is more important than in a standard laboratory or clinical environment.

To address these issues, we have developed a protocol in which a simple psychoacoustic test is conducted remotely and in the laboratory to assess both the consistency of data collected in these environments and the usability of the at-home test with minimal guidance from an audiologist. The Quick Spectral Modulation Detection (QSMD; Gifford et al 2014) test was selected because it is quick (under 4 minutes), can be easily implemented online, and might potentially provide useful information. After online consenting with guidance from an audiologist, cochlear implant users are given a weblink to run a web-based implementation of the QSMD test with the speakers on their device at a “comfortable” loudness. Upon completion, the subjects are asked if they have an iPhone, and if so, would they be willing to download a sound level meter app (NIOSH) with which they could calibrate playback to 65 dB SPL and then repeat the test. Subsequently, the participants would come in person to the laboratory where they would be tested with audiologist help in a properly calibrated soundbooth on both the online and laboratory (EasyQSMD; Landsberger et al., 2019) variants of the test. Subjects are sent home to repeat the at-home measures of QSMD to counterbalance for practice and order effects.

The QSMD measures spectral modulation detection thresholds of CI users using a method of constant stimuli. Using a 3-IFC task, subjects are asked to determine which interval contains a spectral modulation. The process is repeated 6 times for modulation depths of 10, 11, 13, 14, and 16 dB at 0.5 or 1 cycle per octave. Scoring consists of a total % correct identification. At-home testing was conducted via a web-based implementation designed to mimic the windows-based implementation (EasyQMSD). The web-based version was developed in jsPsych and hosted on Cognition.run.

Presently four CI users have completed the first at-home testing session and two CI users have completed all sessions. All subjects were able to collect an uncalibrated measure of QSMD successfully without help or an intervention. It is unclear that any of the CI users were able to successfully calibrate the signal. One participant did not have access to an iPhone, one had troubles installing the app, and two found the app and interface too confusing to use. One unexpected difficulty was that the iPhones of some participants were configured to use large fonts such that the NIOSH software did not render correctly. For the two participants who completed the experiment both at home and in the lab, scores on the QSMD test were poorer at home than in the laboratory. A more complete set of data will be presented at CIAP in which both differences and correlations between at-home and in-lab variations will be analyzed.

1447: TOWARDS A BETTER UNDERSTANDING OF NON-MONOTONIC LOUDNESS GROWTH FUNCTIONS IN COCHLEAR IMPLANT STIMULATION

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Speech intelligibility by cochlear implant (CI) listeners depends on the proper transmission of speech level fluctuations (SLFs). Existing speech-coding strategies rely on the important assumption that SLFs can be conveyed by simple variations in electrical current level. However, we previously reported that this assumption could be violated when the electrical pulse shape was a quadraphasic pulse with cathodic central phases. While increasing the current level of trains of such pulses, CI listeners perceived a loudness decrease at some point in their dynamic range, thereby yielding non-monotonic loudness growth functions on about 40% of their electrodes. One possible explanation arose from modeling studies showing that spikes traveling along an auditory nerve fiber could be blocked when crossing a strongly hyperpolarized region. Such a blocking effect might disrupt the stimulus excitation pattern because the fibers most likely to be blocked would be those close to the electrode. The aims of the present study are to better understand the causes and implications of this phenomenon by testing if the decrease in loudness is truly accompanied by a decrease in neural activity. To do so we measure electrically-evoked auditory brainstem responses at different current levels, and obtain forward-masked excitation patterns of these same stimuli.

Up to now, only 2 and 3 CI users with an identified non-monotonic electrode took part in Experiment 1 and 2, respectively. For both experiments, they were first asked to rank in loudness several 100-pps quadraphasic pulse trains with cathodic central phases differing in current level (spanning the top 75% of their dynamic range) to verify the presence of a non-monotonicity. Experiment 1 measured eABR growth functions using a Biosemi Active 2 EEG system for quadraphasic pulses presented at a lower rate of 40 pps. Experiment 2 measured forward-masked excitation patterns using the same 100-pps quadraphasic stimulus as a masker. Subjects had to detect a short 20-ms probe presented 8 ms after the masker. The probe rate was 250 pps and was different than the masker rate (100 pps) to avoid confusion effects. Masked thresholds were measured at several current levels, including those below, within, and above the loudness reversal. Five probe electrodes were measured located at the masker site, +/- 2 electrodes away from the masker site and +/- 4 electrodes away.

Preliminary data showed non-monotonic eABR input-output growth functions for both subjects, with a reversal occurring at levels consistent with the loudness ranking data. Forward-masked excitation patterns showed an overall decrease in masking in the dip of the non-monotonic function. Interestingly, at levels higher than the dip, the excitation appeared to grow more steeply at sites remote from the masker electrode than at the masker site. These initial measurements show that the amplitude growth of the eABR response is consistent with the subjects' loudness growth, and confirm that the source of the non-monotonic loudness is at or prior to the brainstem. This may be explained (i) either by a decrease in neural activity at the level of the auditory nerve during the loudness reversal or (ii) alternatively by less firing synchrony across fibers, due e.g. to different sites of action potential initiation. The preliminary masking data seem to argue in favor of hypothesis (i) as shown by the decrease in masking occurring in the loudness reversal. Furthermore, elucidating the mechanisms responsible for the loudness reversals observed with quadraphasic stimuli may shed light on loudness growth obtained with the biphasic stimuli used clinically.

1456: INVESTIGATING THE EFFECT OF INTERAURAL ASYMMETRIES ON BINAURAL UNMASKING OF VOCODED SPEECH AND BINAURAL INTEGRATION USING EEG

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Individuals with bilateral cochlear implants (BiCIs) experience reduced binaural benefits compared to normal hearing (NH) listeners. They also frequently demonstrate interaural asymmetries, i.e., differences in speech intelligibility performance across ears. Factors such as neural health and electrode placement have been shown to affect the peripheral encoding of temporal speech information. When these factors differ across ears, they can contribute to performance asymmetries in this population. It is difficult to control for temporal degradation in BiCI listeners, and simulations in NH provide a useful avenue to study its impact. One method for degrading temporal speech information is to compress the dynamic range of the speech stimulus, effectively reducing amplitude modulations in the speech envelope. We hypothesized that interaural asymmetries in dynamic range would negatively impact the binaural system's ability to integrate sounds across ears and perceptually segregate sound sources, leading to reduced binaural unmasking. To test this hypothesis, the present study examined the effect of interaural asymmetries in dynamic range on binaural processing of speech using behavioral and electrophysiological measures in NH individuals listening to CI simulations.

Experiment 1 investigated the effect of interaural asymmetries on binaural unmasking of speech. This paradigm eliminates listeners' ability to use monaural benefits and instead requires listeners to segregate target and masker speech stimuli using only binaural cues. Target stimuli consisted of female-talker IEEE sentences and masker stimuli consisted of female-talker AzBio sentences. Stimuli were processed using a 16-channel vocoder and presented over headphones at 65dB SPL. To simulate symmetric and asymmetric conditions, the dynamic range of the speech signal was compressed independently in one or both ears to 100% (no compression), 71%, 50%, 35%, and 25% of the original dynamic range. Listeners were tested in three conditions: 1) Quiet, target speech presented alone to one ear, 2) Monaural, target and masker speech presented to one ear, and 3) Bilateral, target speech presented to one ear and masker speech presented concurrently to both ears. Both monaural and bilateral conditions were tested at a signal-to-noise ratio of 0dB. Speech intelligibility was measured for all conditions and binaural unmasking was calculated by comparing performance in the monaural and bilateral conditions. Preliminary data show that speech intelligibility worsened with decreasing dynamic range. Additionally, symmetrical reductions in dynamic range elicited more unmasking than asymmetrical reductions. This indicates that interaural asymmetries in dynamic range limit binaural benefits in NH listeners, which may have important implications for BiCI listeners.

Experiment 2 will use electroencephalography (EEG) to investigate neural markers of binaural integration. Here we plan to examine the effect of symmetric and asymmetric dynamic range on neural recordings to determine whether insufficient integration contributes to reduced binaural unmasking in conditions with large interaural asymmetries. Stimuli will be processed using the same vocoder and dynamic range compression method outlined in experiment 1. Together these experiments will help elucidate mechanisms underlying poor binaural outcomes in BiCI users with interaural asymmetries and contribute to improved clinical management of these patients.

1495: CONSIDERATION OF THE OPTIMAL AMOUNT OF COMPRESSION IN THE CI AMPLITUDE MAPPING FUNCTION

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Increasing electrical current in a cochlear implant (CI) stimulus results in a power law loudness growth. In an attempt to correct this and to achieve loudness growth similar to that of normal hearing (NH) listeners, the speech processor's acoustic-to-electric amplitude mapping function (the loudness growth function, or LGF) is typically compressive. In addition, the LGF maps the larger input dynamic range to a smaller electric dynamic range. The objective of the LGF is to optimise the utilisation of the available electric dynamic range.

The amount of compression applied by the LGF is determined by a parameter referred to as the Q-value in Nucleus speech processors, while the c-value of the maplaw function in Med-El speech processors fulfils the same purpose. The question addressed here is how to determine the optimal amount of compression.

Loudness growth in free-field listening conditions were considered first. Experiments were conducted with seven CI listeners (Nucleus CI users) in which loudness growth was measured using a magnitude estimation method. Stimuli were speech-shaped noise presented in quiet. Experiments were repeated for Q-values that covered the available range of compression in Nucleus speech processors.

Summarising results across listeners, data show that normal loudness growth is seldom obtained with any settings of the speech processor, and that varying the amount of compression across the entire range of Q-values 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. A Q-value of 10 (most compressive) was interpreted as being "clear", but background noise was noted as being distracting. A value of 50 (least compressive) was considered too soft and some participants had difficulty understanding conversational speech. The strongly varying subjective sound quality across Q-values suggested that another measure for the effectiveness of the compression function, not based on loudness growth, may be required. A different measure was developed that reflects how well the available dynamic range is used. Using a modelling approach, two independent metrics were defined to rank the effectiveness of Q-values in presenting a CI listener with intensity information. These two scores were combined in a weighted sum to determine an overall score that reflects how well the available dynamic range is used. From this, an optimal value for Q could be predicted. This predicted value was compared to previous research in which phoneme recognition was tested when the amount of compression was varied. Predicted optimal Q values were found to correspond well to previous findings.

Speech Perception – Featured Talks + Posters

Featured Recorded Talk:

1460: DORSOLATERAL PREFRONTAL CORTEX SUPPORTS SPOKEN WORD RECOGNITION IN LISTENERS WITH COCHLEAR IMPLANTS: EVIDENCE FROM HIGH-DENSITY DIFFUSE OPTICAL TOMOGRAPHY

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Abstract
There is tremendous variability in how well listeners with cochlear implants (CIs) understand speech due to factors such as the degraded quality of sounds, especially in the presence of background noise, the duration of deafness, and the age at which the implant is received. Multiple studies suggest that listening to acoustically degraded speech increases cognitive demand, contributing to the increased listening effort. In adults with normal hearing, increased cognitive demand has been associated with activity in the left dorsolateral prefrontal cortex (DLPFC), a region involved in cognitive control across a wide range of domains. Unfortunately, the organization of cortical language networks in listeners with CIs is not well understood, in part, due to difficulties obtaining functional neuroimaging data in this population. Thus, direct evidence for what brain networks might be recruited to support successful understanding is lacking. Here we measured regional brain activity using high-density diffuse optical tomography (HD-DOT), a quiet and non-invasive imaging modality with a comparable temporal and spatial resolution to fMRI. This HD-DOT system has previously been validated in mapping the brain networks supporting speech perception in healthy adults. In this study, we investigated the brain networks supporting spoken word recognition in quiet in 19 right ear CI users and 17 age and sex equivalent control cohort. Participants heard lists of spoken words, presented in quiet, and instructed to listen attentively. A subset of participants also performed a spatial working memory task used to localize domain-general regions of DLPFC. Our results show decreased left and right auditory cortex activations in the CI users compared to controls and an increase in the left DLPFC in CI users. Our results provide the first high-quality fMRI-like measurement of the cortical network organization in the CI user population. They are consistent with a compensatory framework in which CI listeners need to recruit regions of DLPFC to understand speech successfully.

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Featured Recorded Talk:

1361: EFFECTS OF NEURAL ADAPTATION AND ADAPTATION RECOVERY ON WORD RECOGNITION IN COCHLEAR IMPLANT USERS.

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Background: Studies on the effect of stimulation pulse rate on speech perception in cochlear implant (CI) users show inconsistent results. Some studies show a preference for higher stimulation rates above 1000 pulses per second (pps) (Nie et al., 2006), others suggest lower rates below 1000 pps are preferred (Balkany et al., 2007), while still others show no difference in performance (Friesen et al., 2005). The mechanism underlying the inconsistency of this rate effect is unknown. We propose that variations among CI users in neural adaptation and/or recovery from neural adaptation at the cochlear nerve (CN) may partially account for the inconsistency of the rate effect on speech perception. We hypothesize that excessive neural adaptation and/or less efficient recovery from neural adaptation at the CN could lead to poor speech perception in CI users, presumably due to their negative effects on the neural representation of temporal envelope cues. To test this hypothesis, this project used electrophysiological measures of the electrically evoked compound action potential (eCAP) to study the associations of word/phoneme recognition with neural adaptation and adaptation recovery at the level of the CN in postlingually deafened adult CI users.

Methods: To date, 15 adults have been recruited and tested for this study. Four participants were tested bilaterally for a total of 19 ears tested. All subjects were implanted with a Cochlear™ Nucleus® device in the test ear(s) with full electrode array insertions and used a pulse rate of 900 pulses per second (pps) per channel in the programming map that they used on a daily basis. Electrically evoked compound action potentials (eCAPs) were used to measure neural adaptation and adaptation recovery at multiple electrode locations across the electrode array. The stimulus was a 100-ms pulse train stimuli with a pulse rate of 900 pps. For each subject, monaural word and phoneme recognition scores were measured in quiet and in noise at +5 dB signal-to-noise ratio (SNR) using Maryland consonant-vowel nucleus-consonant (CNC) word lists. One-tailed, Spearman's rank correlations were used to assess the relationship between eCAP results and word/phoneme recognition scores.

Results: Substantial inter-subject variations in the amount and the speed of neural adaptation as well as the amount and the speed of recovery from neural adaptation were observed. Our results revealed non-significant correlations between word/phoneme recognition scores and the amount and the speed of neural adaptation at the CN. The speed of adaptation recovery significantly correlated with word and phoneme recognition measured in noise, and the amount of adaptation recovery correlated with phoneme recognition in noise ($p < .05$). Greater and faster neural adaptation recovery correlated with better word/phoneme recognition.

Conclusions: Our preliminary results suggest that adaptation recovery of the CN is an important factor for speech perception in CI users. Variations in the amount and the speed of recovery from neural adaptation might account for the varied effects of pulse rate on speech perception outcomes among CI users.

Acknowledgments: This work was supported by the R01 grant from NIDCD/NIGMS (1R01DC016038).

1309: EFFECTS OF MASKER INTELLIGIBILITY AND TALKER SEX ON SEGREGATION OF COMPETING SPEECH IN ADULTS AND CHILDREN WITH NORMAL HEARING AND IN CHILDREN WITH COCHLEAR IMPLANTS

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Children with normal hearing (CNH) have greater difficulty segregating competing speech than do adults with normal hearing (ANH). Children with cochlear implants (CCI) have greater difficulty segregating competing speech than do CNH. In the present study, speech reception thresholds (SRTs) in competing speech were measured in Chinese Mandarin-speaking adults with normal hearing, children with normal hearing, and children with CIs. Target sentences were produced by a male Mandarin-speaking talker. Maskers were time-forward or -reversed sentences produced by native Mandarin-speaking male (different from the target) or female or by a non-native English-speaking male. A closed-set task similar to the coordinate response measure (CRM) was used to measure SRTs, using Chinese and English matrix-style stimuli.

SRTs were lowest (best) for the ANH group, followed by the CNH and CCI groups. Masking release (MR) was comparable between the ANH and CNH groups, but much poorer in the CCI group. For the ANH and CNH groups, MR was generally best with non-native and/or reversed speech maskers; there was very little sensitivity to differences in MR cues for the CCI group. Interestingly, MR was often sometimes greater in the CNH group than in the ANH group.

The temporal properties differed among the maskers due to speaking rate and temporal envelope differences between forward and reversed speech. These temporal properties were characterized as the mean positive target-to-masker ratio (TMR) between the target and masker sentences. The peak amplitude within a rolling 300-ms analysis window (broadband) was calculated for target and masker sentences at 0 dB TMR. The amplitude difference between the target and masker was calculated for each window and only the positive values were retained (positive TMR); the positive TMR values were averaged across all windows and target-masker combinations and termed as the “mean positive TMR.” Using this metric, the temporal properties of the maskers were significantly associated with SRTs for the CCI and CNH groups, but not for the ANH group. While the temporal properties of the maskers were significantly associated with MR for all three groups, the association was stronger for CCI and CNH groups than for the ANH group.
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1310: PROSODY PERCEPTION IN COCHLEAR IMPLANT USERS AND VOCODER SIMULATIONS: A META-ANALYSIS

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Prosody forms an important part of spoken language. Linguistic prosody, for instance, conveys information on the syntactic and semantic properties of speech, whereas emotional prosody conveys information on the emotional state of a speaker. Both forms of prosody utilise a common set of acoustic cues - most prominently fundamental frequency (f_0), intensity, and duration - and listeners are able to draw on these cues when identifying the information conveyed by these different forms of prosody. Identifying this information can be challenging for cochlear implant (CI) users because the electric speech signal transmitted through a CI is highly lacking in fine spectrotemportal detail, hindering their ability to draw on acoustic cues - particularly f_0 - that are readily available to normal hearing (NH) individuals. Relatively few studies have assessed how CIs or their acoustic vocoder simulations influence the perception of prosody.

We present our recently published meta-analysis on the identification of linguistic and emotional prosody in CI users and with vocoder simulations. In this study, we quantified the results of 64 studies that assess the influence of CIs and vocoder simulations on prosody identification; studies were included in the meta-analysis if they reported results of experimental group studies investigating how accurately CI users and/or vocoder simulation listeners identify linguistic and/or emotional prosody in quiet compared to NH listeners. This meta-analysis shows whether the impact CIs and vocoder simulations have on prosody identification is robust across studies whilst taking differences in the experimental design and sample sizes between these individual studies into account. The results provide a more comprehensive overview of the effect of electric hearing on prosody identification than would be possible in individual studies.

A multilevel linear random-effects model revealed a large negative effect size for the influence of CIs and vocoder simulations on prosody identification, indicating that CI users and vocoder simulation listeners identify prosody less accurately than NH listeners. A multilevel linear mixed-effects model subsequently revealed significant differences in the effect of electric hearing, which depended on whether listeners identified linguistic prosody or emotional prosody and on whether or not the stimuli incorporated changes in f_0 as a cue to the prosodic information. Moreover, the model showed that the effect of electric hearing did not significantly differ between studies with CI users and studies with vocoder simulation listeners, indicating that the vocoder simulations of these studies approximate the performance of CI users well. Taken together, the meta-analysis revealed a robust impact of CIs and vocoder simulations on prosody identification, where electric hearing limits prosody identification. This effect can mainly be attributed to the poor transmission of f_0 through the degraded electric speech signal of CIs and their acoustic vocoder simulations.

1311: NON-NATIVE PROSODY PERCEPTION IN COCHLEAR-IMPLANT-SIMULATED SPEECH

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Speakers use prosody-related acoustic cues such as variation in fundamental frequency (f_0), intensity, and duration to produce lexical stress and linguistic focus, which listeners in turn can utilise to identify the stressed syllable or focused word. For instance, a given syllable of a word is identified as stressed depending on its perceived prominence relative to another syllable. Similarly, a word in focus in an intonation phrase is realised with localised phonetic prominence relative to the words around it. Correctly identifying the stressed syllable or the word in focus can be more challenging for cochlear implant (CI) users than for normal hearing (NH) individuals. That is, even though CI users benefit from the electric input of the device, speech perception with electric hearing differs from speech perception with normal (acoustic) hearing. The electric speech signal is highly lacking in fine spectrotemporal detail, resulting in a lower quality of transmission of acoustic cues - particularly f_0 - in this signal than in an acoustic speech signal. As a result, utilisation of prosody-related acoustic cues is hindered, and prosody identification becomes compromised. An additional challenge can be expected for CI users perceiving prosody in a non-native language, as the utilisation of prosody-related acoustic cues may differ between the native and non-native language or may be less efficiently processed in the non-native language.

We present the results of two experiments on non-native prosody perception in CI-simulated speech (i.e. an acoustic approximation of electric hearing implemented by a noise-band vocoder). In one experiment, participants performed a listening task assessing the influence of a CI simulation on lexical stress identification; native Dutch listeners were presented with Dutch and English words differing in lexical stress and were asked to indicate whether the first syllable or the second syllable was stressed. Results indicate that f_0 is more effectively utilised in the non-CI-simulated condition than in the CI-simulated condition and consequently that lexical stress identification is significantly compromised in the CI-simulated condition. Moreover, listeners used prosody-related acoustic cues differently in the native language compared to the non-native language; listeners relied more heavily on f_0 changes in Dutch than in English. In the other - currently ongoing - experiment, participants complete an online experiment assessing how a CI simulation influences the interpretation of prosodically marked sentential focus in a non-native language; native Dutch and native English listeners are presented with English sentences differing in prosodically marked sentential focus and are asked to indicate which of four possible context questions the speaker answered. We expect that listeners are less accurate and less efficient for the CI-simulated stimuli compared to the non-CI-simulated stimuli and that non-native listeners are less efficient than native listeners. Taken together, these vocoder simulation studies indicate that CI users may encounter challenges in prosody perception in a non-native language.

1316: EFFECTS OF INTER-AURAL FREQUENCY MATCHING ON SPATIAL RELEASE FROM MASKING IN SIMULATIONS OF BILATERAL COCHLEAR IMPLANTS

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For bilateral cochlear implant (CI) users, the position of electrodes and their proximity to healthy neural populations may differ across ears (e.g., differences in electrode insertion depth). Clinically, the same acoustic frequency allocation table (FAT) is typically assigned to both ears. This may result in an inter-aural frequency mismatch, which has been shown to limit the perception of spatial cues and negatively affect spatial release from masking (SRM). Adjusting the FAT may reduce inter-aural mismatch and improve SRM. However, this may also introduce low-frequency information loss in one or both ears depending on differences in insertion depth, which may negatively affect overall speech understanding. The present study explored the trade-off between reduced inter-aural frequency mismatch and the loss of low-frequency information for segregation of competing speech in normal-hearing (NH) participants listening to acoustic simulations of bilateral CIs.

Speech reception thresholds (SRTs) were measured for target sentences produced by a male talker in the presence of two different male talkers. The target sentence was always presented directly in front of the listener, and the maskers were either co-located with the target or were spatially separated (+90°, -90°). Stimuli were presented via headphones and were virtually spatialized using non-individualized head-related transfer functions. The bilateral CI simulations were 16-channel sinewave vocoders. The length of the simulated electrode array was 20 mm, and three different insertion depths were simulated in each ear (27, 25, and 21 mm); thus the degree of inter-aural mismatch was 0, 2, or 6 mm. Two FAT conditions were compared: 1) clinical FAT (200-8000 Hz), and 2) matched FAT (where the FAT was adjusted to match the frequency corresponding to electrode position in each ear, according to insertion depth).

Results showed that the matched FAT provided lower (better) SRTs than clinical FAT, regardless of the insertion depth or spatial configuration. The largest improvement in SRTs with the matched FAT was observed for the largest inter-aural mismatch (6 mm). SRM significantly depended on inter-aural mismatch for the clinical FAT, but not for the matched FAT. These simulation results suggest that minimizing inter-aural mismatch by adjusting the FAT may benefit overall SRTs and SRM, especially when there is a large difference in insertion depth across ears. These benefits were observed despite substantial low-frequency information loss in ears with shallow insertion. Estimates of electrode position in each ear may guide optimal FATs to improve segregation of competing speech with or without spatial cues for bilateral CI users.

1330: THE EFFECTS OF LEXICAL ACCESS, ACOUSTIC AND LINGUISTIC VARIABILITY, AND VOCODING ON VOICE CUE PERCEPTION

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Differences in voice cues, such as fundamental frequency (F0) and/or vocal-tract length (VTL), can facilitate speech communication in challenging conditions. In cochlear-implant (CI) users, the spectrotemporal degradations imposed by electrical stimulation hampers the ability to identify differences in voice cues. In particular, the decoding of acoustic cues that overlap in their support of both voice perception and phonemic categorization might become particularly challenging as the cues could be mistaken for one another. In other words, there could be a stronger interaction between linguistic and indexical content when the stimuli are degraded to mimic electrical stimulation.

Fifteen normal-hearing participants performed a three-interval, three-alternative forced choice (3AFC) adaptive task to measure just-noticeable-differences (JNDs) in F0 and VTL. To evaluate the role of lexical content, the items used in the task were either words or time-reversed words. Additionally, the use of lexical content was either promoted (when the items were different across intervals) or not (when the same item was used). Finally, stimuli were presented without or with vocoding (12-band vocoder with low or high spread of excitation).

Results show that JNDs for both F0 and VTL were significantly smaller (better) for non-vocoded compared to vocoded speech, and for fixed compared to variable items. These two factors interacted: for F0, the effect of item variability on the JNDs decreased when the vocoder degradations increased; whereas for VTL, the effect of item variability on JNDs was slightly magnified through vocoding. Lexical content (forward vs reversed) affected JNDs for the VTL cue and in the variable word condition, but had little effect on the F0 JNDs.

In conclusion, lexical content had a positive top-down effect on VTL perception when acoustic and linguistic variability was present, but not on F0 perception. This suggests that phonotactic properties do impact VTL perception. Interestingly, the lexical advantage not only persisted in the most degraded conditions, vocoding even enhanced the effect of item variability. This suggests that top-down semantic or phonotactic processing could be used by CI-users as a compensatory strategy. Future research has to show that relying on lexical content, or linguistic relationships, could benefit CI-users, by improving their voice discrimination, and in turn performances on tasks relying on voice perception, such as gender categorization and speech perception in speech maskers.

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1332: THE EFFECT OF VOICE FAMILIARITY VIA SHORT TERM TRAINING ON VOICE CUE SENSITIVITY AND LISTENING EFFORT IN NORMAL AND VOCODER-DEGRADED SPEECH PERCEPTION

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Speech perception in non-optimal listening conditions, such as at a cocktail party, can be both challenging and effortful for cochlear-implant (CI) users. Nevertheless, voice segregation can facilitate speech perception in multi-talker settings, and familiar voices can further contribute to this. While effective use of voice cues such as fundamental frequency (F0) and vocal-tract length (VTL) is important for voice segregation, it is not yet clear if voice familiarity may benefit perception of these voice cues, and affect listening effort, especially under the degraded conditions of vocoder. In the current study, a short-term training was implemented, as a first-step for voice familiarity.

During voice training, a recording of a book segment (Dutch translation of “The Twits” by Roald Dahl) was presented for approximately 30 minutes by either a female or a male speaker’s voice. To ensure attention, listeners had to answer questions related to content at regular intervals. Following voice training, Just-Noticeable-Differences (JNDs) were measured from normal hearing (NH) adults with a 3 AFC adaptive paradigm for both trained voice and the opposite gender untrained novel voice, in both normal and vocoder-degraded versions (12-band, 12th order Butterworth filter). Effects of voice familiarity (trained and untrained voice), vocoding (non-vocoding and vocoder-degraded) and item variability (fixed or variable consonant-vowel triplets presented across three tokens) on voice cue sensitivity (F0+VTL JNDs) and listening effort (pupillometry measurements) were analyzed.

Preliminary results indicated that JNDs were affected by vocoding and item variability. Overall, JNDs were larger for vocoding conditions than for non-vocoding conditions. Within non-vocoding and vocoding conditions, JNDs were larger when variable items were presented compared to fixed items, for both trained and untrained voices. There was no clear effect of voice familiarity on JNDs with the limited data we have. However, the pupil dilation response was largest when listening to untrained vocoded stimuli, for both fixed and variable items. Overall, larger pupil responses were observed for the vocoded compared to the non-vocoded conditions, and for the variable compared to the fixed item conditions. Within the vocoded conditions the untrained voices resulted in larger pupil responses, implying that more effort was put in listening to an untrained voice compared to a trained voice. The only exception was when fixed items were presented during non-vocoded conditions, then the pupil response to the untrained voice was smallest, implying that less listening effort was put in listening to an untrained voice than to a trained voice. These preliminary findings indicate that, while there seems a possibility that the current voice training might not increase sensitivity to voice cues, a reduced listening effort with voice training may still indicate benefits for vocoded speech perception.

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1335: CAPTURING VARIATIONS OF SPEECH: EMOHI AND VARIANTS SPEECH MATERIALS

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Speech perception in cochlear implant (CI) users is commonly assessed using idealized speech materials – carefully articulated speech produced by a single talker – in quiet. However, speech perception involves not only what is being said, but also how it is being said and who is saying it. A talker's pronunciation of a word may vary depending on the context, leading to within-talker variability in emotion, speaking style and rate, among others. Additionally, pronunciation differences across talkers, with diverse language backgrounds and developmental histories, result in substantial between-talker variability. For children and adults with CIs, the perception of within- and between-talker differences can remain a significant challenge. CI users often display poor discrimination of both within- and between-talker differences in voice and speech cues, and have difficulty accommodating variability in speech recognition. Yet, our understanding of CI users' perception of within- and between-talker variability is still limited, partially due to the lack of easily available speech materials. For spoken Dutch in particular, current publicly available corpora do not offer a wide variety of materials with representative within- or between-talker variability.

To address this need, the dB SPL Lab at the University Medical Center Groningen and collaborators have developed two new sets of speech materials. First, the EmoHI corpus was developed for testing vocal emotion recognition, representing an important real-life source of within-talker variability. High-quality audio recordings were collected from 3 male and 3 female native speakers of Dutch. Each speaker expressed three core emotions - happy, angry, and sad – in pseudospeech, making the materials suitable to use across different languages. Data collected with normal-hearing Dutch and English school-age children and adults as well as prelingually deaf Dutch CI children showed the applicability of the test for differing participant groups [1]. The EmoHI test materials are freely available for research [2]. Second, the VariaNTS (Variatie in Nederlandse Taal en Sprekers) corpus was developed to maximize both linguistic and talker variability. The VariaNTS spoken Dutch corpus contains high-quality audio recordings of 1000 items from 11 linguistic subcategories, produced by 8 male and 8 female native speakers of standard Dutch [3]. Materials include nonwords, real words, and meaningful and anomalous sentences. Along with the materials, the corpus offers item-specific details such as word frequencies, neighborhood densities and phonotactic probabilities, as well as demographic details for each talker. The VariaNTS materials are freely available for research [4]. The EmoHI and VariaNTS materials were developed to be used for the assessment of emotion recognition and speech perception in clinical and academic settings. Importantly, these materials were designed to include within- and between-talker variability that characterize everyday listening environments. By doing so, we aim to facilitate future research on speech perception in children and adults with CIs. The development and structure of these materials and their potential applications will be presented.

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1354: A FRAMEWORK FOR CONDUCTING SPEECH INTELLIGIBILITY TESTS REMOTELY

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The COVID-19 pandemic has made human-subject based research activities challenging as many in-person studies were suspended to prevent further spread of the virus. Recent studies have proposed frameworks for conducting speech intelligibility tests remotely in normal hearing listeners (Merchant et al., 2021) and cochlear implant (CI) users (Sevier et al., 2019). However, to the best of our knowledge, no at-home framework has been validated for normal hearing listeners performing sentence recognition tasks using vocoded speech.

We developed a remote study protocol that includes electronic consent, a standalone application to perform listening tests, and subject payments. We developed a computer application that allows subjects to run listening tests remotely using their own computers. The application was developed using MATLAB Compiler™, which allows for the execution of a MATLAB® generated program without requiring a full MATLAB® installation. This application is compatible with both Windows and macOS operating systems. The application presents subjects with a series of sentences and prompts them to type in free form responses, which are saved for offline analysis. Research electronic data capture (REDCap) (Harris et al., 2009) was used to administer electronic consent forms and collect demographic information. Subjects were financially compensated by sending physical checks or electronic gift cards.

To validate the remote framework, we conducted speech intelligibility tests in normal hearing subjects using vocoded speech. During each study session, we met remotely with participants to guide them through the installation process, as well as the listening test. We tested speech intelligibility in anechoic and reverberant listening environments and compared the remote study results to those obtained in-lab. The results demonstrated higher levels of speech intelligibility for our remote experiments as compared to our in-lab experiments. Future work will aim to refine the remote framework to reduce inter-subject variability.

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1365: TALKER EFFECTS IN THE PERCEPTUAL LEARNING OF DEGRADED SPEECH

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New cochlear implant (CI) users face an enormous challenge of learning to adapt to the spectro-temporally degraded and distorted signal delivered by the CI, while also experiencing speech from a variety of talkers, with different voices and speech characteristics, in everyday environments. Previous research has shown that individual talkers vary greatly in intelligibility (both initially and after exposure) for CI users as well as normal-hearing (NH) listeners listening to vocoded speech. However, it is still unclear how learning depends on a talker's voice or speech characteristics, and the extent to which it is talker-specific. Previous studies, focused on the perceptual learning of vocoded speech in NH listeners, have found little evidence for talker-specific effects, suggesting that deficits in the perception of talker details in vocoded speech may limit talker effects on learning.

The current study examined talker effects on the perceptual learning of vocoded speech. In particular, we aimed to determine whether improvements in sentence recognition following single-talker exposure to vocoded speech vary across training talkers and to what extent improvements are talker-specific. An online training experiment involved a training block and test block. In the training block, participants transcribed 80 sentences produced by one of four native speakers of Dutch (2 females and 2 males) from the VariaNTS speech corpus. The test block consisted of 80 new sentences produced by all four talkers in multi-talker babble at +10 dB SNR. The experiment was carried out using 8-channel noise-vocoded sentences, varying in sentence predictability (high or low). Eighty younger (18-40 yr), native Dutch speakers with self-reported normal hearing were randomly placed into one of the four training groups. Participants also passed an online headphone screening test. Performance in the test block was compared across training groups and test talkers.

First, examining the effects of training talker on test performance, preliminary results demonstrated that sentence recognition accuracy in the test block differed by training group (i.e. training talker). The two groups trained with the female talkers showed more accurate overall test performance than the two groups trained with the male talkers. Crucially, this did not correspond to training performance – that is, the female-trained groups were not the most accurate in the training block, suggesting that they were not just better overall at recognizing vocoded speech. Second, examining performance across talkers in the test block, results showed that the two groups trained by the female talkers also showed more accurate performance for the female talkers in the test block. Similarly, the two groups trained by the male talkers were also relatively more accurate for the male talkers in the test block.

Together, these preliminary results suggest that the perceptual learning of vocoded speech, with limited exposure, depends on the training talker and is talker-specific. Future studies will be carried out to determine the extent to which these effects are specific to the talkers used in the current study, as well as the voice and/or speech characteristics that may promote greater learning of vocoded speech. Future studies will also determine applicability of findings to adult CI users, with implications for counseling and auditory training. Adaptation to a new CI may not be similarly improved by experience with any single talker, depending on the talker's speech and/or voice characteristics. Exposure to multiple talkers with different voice and speech properties, either in everyday life or via targeted training, may promote robust adaptation to a new CI.

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1367: EFFECTS OF MASKER TYPES ON SPEECH RECOGNITION BY COCHLEAR IMPLANT USERS AND NORMAL HEARING LISTENERS

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For normal-hearing (NH) listeners, speech reception thresholds (SRTs) are typically lower (better) in dynamic maskers (e.g., gated noise, multi-talker babble, competing speech) than in steady-state noise (SSN). In contrast, SRTs are typically lower in SSN than in dynamic maskers for cochlear implant (CI) listeners. The poorer spectro-temporal resolution is thought to underlie this greater susceptibility to dynamic maskers. However, dynamic maskers can also differ in terms of informational masking, such as temporal envelope properties, the availability of temporal fine structure (TFS) cues, lexically meaningful content, number of maskers, etc. The goal of the present study was to evaluate the effect of different masker characteristics on SRTs in adult Chinese, Mandarin-speaking NH and CI listeners. The maskers included three noise maskers (i.e., SSN, pulse amplitude modulated noise, temporal envelope modulated noise) and six speech maskers (i.e., one- or two-talker forward, one- or two-talker reversed, one-talker forward with one-talker reversed, and six-talker speech babble). The noise maskers generally contained energetic and/or envelope masking, but without temporal fine structure (TFS) information. The speech maskers contained energetic, envelope, irrelevant or irrelevant informational masking, with TFS information.

Consistent with previous studies, mean SRTs were significantly lower for the NH group than for the CI group in all masker types. For the NH group, SRTs were significantly lower for maskers without TFS information or irrelevant lexical information than for SSN, suggesting that the lack of TFS information and/or irrelevant lexical information allowed for better segregation of the target speech. However, SRTs were significantly higher for two-talker speech maskers with relevant lexical information than for SSN. For the CI group, SRTs were significantly higher for time-forward speech maskers than for SSN regardless of the number of speech maskers. Compared to reversed speech, SRTs were generally higher with the forward speech, whether with one or two maskers, suggesting greater masking associated with relevant lexical information in both groups. For the CI group, SRTs with the dynamic maskers were compared to SRTs with SSN. There were significant correlations between dynamic maskers and SSN for all dynamic maskers expect one-talker speech masker (both forward and reversed). The mean regression slopes were 0.93 for noise maskers and 0.47 for speech maskers. This suggests that masked speech understanding in CI listeners can best be characterized using both SSN (energetic masking) and one-talker speech masker (energetic and informational masking).

1376: BIMODAL AND AUDIOVISUAL BENEFITS OF SPEECH INTELLIGIBILITY IN COCHLEAR IMPLANT USERS WITH CONTRALATERAL ACOUSTIC HEARING

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Mandatory mouth-covering masks in times of the present pandemic remove lip-reading cues in direct one-to-one communication. Such visual cues, however, are known to alleviate speech understanding in noise, especially for cochlear implant (CI) users. This study investigated this audiovisual benefit in speech intelligibility in CI users with and without access to contralateral acoustic hearing. Nine CI users (seven bimodal, two single-side deaf) and six normal-hearing listeners (as controls) were tested using the HSM sentence test in noise with and without time-aligned visual stimuli. Stationary and fluctuating noise was used, and the “bimodal benefit” was assessed by presenting the stimuli either binaurally or monaurally to each ear (and masking the opposite ear).

The results indicated an audiovisual benefit of 11.1 % over all tested conditions in CI users and an audiovisual benefit of 10.8 % in the normal-hearing control group, which did not strongly depend on the type of noise (stationary or fluctuating). For the CI users, a significant bimodal benefit (averaged over audio-only and audiovisual conditions) of 16.8 % in comparison to acoustic-only listening, and of 47.5 % in comparison to electric-only listening was observed. Furthermore, there was no significant interaction between the factor modality (monaural or binaural) and the factor visual information. This indicates that the audiovisual benefit is independent of the benefit that the listeners in this study obtained from the access to acoustic information contralateral to the CI.

1388: EFFECTIVENESS OF SIX CLINICAL SPEECH ENHANCEMENT STRATEGIES FOR CI USERS

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Aim: Cochlear implants (CI) can offer good speech recognition in quiet environments. However, in noisy conditions the performance of CIs degrades sharply. In the present study we report on 6 speech enhancement strategies to improve speech recognition in noise, namely: (1) fitting of a a contralateral HA; (2) an adaptive monaural beamformer (MB, or 'UltraZoom'); (3) a fixed binaural beamformer (BB, or 'StereoZoom'); (4) a stationary noise reduction algorithm (SNRA, or 'ClearVoice'); (5) a transient impulse noise reduction algorithm (TNRA); and (6) an algorithm that targets the electronic noise generated internally in the processor (ENRA, or 'SoftVoice').

Methods: The performance of the speech enhancement strategies was tested in unilaterally implanted Advanced Bionics CI users by determining the speech recognition threshold (SRT) with the Matrix test. Different auditory scenes were used appropriate for each specific algorithm. Bimodal hearing was tested in stationary and babble noise, beamforming in babble noise, SNRA in stationary noise, TNRA in restaurant noise with impulse noise (dish clatter), and ENRA in quiet.

Results: Tested against omnidirectional processor microphone settings, MB and BB significantly improved the SRT by 2.6 and 2.9 dB in bimodal listeners, respectively (Stronks et al. 2021a). HA use improved SRTs by 0.8 dB in stationary noise and 1.7 dB in babble noise. The difference could be related to the enhanced perception of temporal fine structure when listening bimodally (Stronks et al. 2020). Tested against Tmic, BB improved the SRT significantly by 1.3 dB in a group of CROS users, but MB did not affect the SRT significantly. In bimodal listeners, SNRA did not significantly affect the SRT either alone or in combination with MB and BB (Stronks et al. 2021a). The clinically available TNRA did not significantly affect the SRT in a group of unilateral CI users, whereas an experimental personalized multiband variant of TNRA significantly improved the SRT by 1.3 dB (Stronks et al. 2021b). ENRA improved the SRT by 2.0 dB (Stronks et al. 2021c).

Conclusion: Beamforming was generally effective, depending on the fitting and/or the reference microphone settings used. Bimodal hearing improved SRTs and especially so in babble noise. SNRA and TNRA were ineffective, but a personalized multiband TNR variant proved significantly effective; ENRA improved the SRT significantly as well.

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1402: SPREAD PRE-COMPENSATION CODING STRATEGY FOR COCHLEAR IMPLANT USERS TO IMPROVE SPEECH UNDERSTANDING IN NOISE

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Speech understanding in noise remains one of the most important challenges for cochlear implant (CI) recipients. Spread of electrical stimulation in the cochlea, which reduces the independence of the different frequency channels, is considered one of the major bottlenecks limiting speech understanding in noise.

Spread Pre-compensation Advanced Combination Encoder (SPACE) attempts to compensate for the spread of neural excitation (Bolner et al 2020). SPACE applies a model of spread of excitation to predict the neural excitation pattern in the cochlea. It chooses channels, and their amplitudes, so that the predicted excitation pattern best approximates the spectral profile of the input spectrum. The present study evaluated two flavors of SPACE where SPACE-boost alters only channel selection but not the magnitudes.

Fourteen CI recipients participated in a take-home trial using Nucleus 7 sound processor with two investigational SPACE programs along with ACE as comparator. Early results reveal significant speech in noise benefit for SPACE programs along with equivalent speech understanding in quiet. Paired sound quality comparison shows no significant differences in quality scores compared to ACE.

SPACE and SPACE-boost provide promising speech in noise benefit; however, more research is needed to investigate its acceptance and effectiveness in larger population.

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1403: COMPARING FIXED AND INDIVIDUALIZED CHANNEL INTERACTION COMPONENTS FOR SPEECH PERCEPTION WITH DYNAMIC FOCUSING COCHLEAR IMPLANT STRATEGIES

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Previous results on the speech perception benefits of dynamic focusing cochlear implant strategies have been mixed. In these studies, channel interaction components (K), determining the rate of change for the degree of current focusing (σ) according to input level, were fixed across participants and channels. K increases with electrode-to-neuron distance, and if the fixed K differs from what would be optimal, then loudness growth could differ from the expected acoustic to electric charge map. This may result in suboptimal loudness growth, and consequently, suboptimal speech perception. This study examined whether individualizing K for each channel improved speech perception relative to fixed K and monopolar strategies.

Ten adult cochlear implant recipients have participated in this laboratory study thus far, testing eleven ears. Participants were programmed with three 14-channel strategies matched for pulse duration, pulse rate, filter settings and loudness. The strategies were monopolar, dynamic partial tripolar (σ = 0.8 at threshold and 0.5 at most comfortable level) with K fixed to 0.9, and the same dynamic partial tripolar strategy with K estimated for each channel using most comfortable loudness levels. Participants had 15 minutes of listening experience with each strategy.

Sentence recognition, scored for key words, and vowel identification was measured with each strategy at 60 dB SPL equivalent in quiet and in four-talker babble noise. The signal-to-noise ratio was adjusted so that monopolar performance was between 40-60% for word recognition, and 60-80% for vowel identification. Ratings on clarity and ease of listening were also obtained.

Preliminary analyses showed no group mean differences in word recognition or vowel identification, in quiet or noise, between the three strategies. There were also no group mean differences in ratings of clarity and ease of listening, in quiet or noise, between the three strategies. These initial findings suggest no overall laboratory benefit to individualizing channel interaction coefficients in dynamic focusing strategies. There was, however, considerable individual differences between participants in speech perception measures and ratings, as in previous studies. Duration of hearing loss was moderately correlated with vowel identification in noise benefit for both dynamic focusing strategies relative to monopolar strategies. Other factors related to individual benefit are being explored. Future studies will employ take-home trials to facilitate acclimatization in the evaluation of such strategies.

Funding
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1414: REDUCED VOICE PITCH DISCRIMINATION AND VOCAL EMOTION RECOGNITION ACROSS THE LIFESPAN IN ADULTS WITH SELF-REPORTED NORMAL HEARING

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Compared to normal-hearing (NH) listeners, listeners with a cochlear implant (CI) have been shown to perform worse on vocal emotion recognition. In addition, CI listeners are less sensitive to differences in fundamental frequency (F0) and vocal tract length (VTL), which are two important voice cues that play a role in a speaker's perceived gender and in distinguishing individual speakers. Furthermore, differences in mean F0 can be used as a cue in vocal emotion recognition.

While the difficulties that CI listeners experience during voice and speech perception may mainly arise from the degraded signal they receive, these listeners are also typically of a more advanced age compared to the NH control listeners. As such, it is not always clear to what extent general aging effects contribute to the reduced performance measured in CI listeners. Indeed, various studies have reported a decline in emotion recognition abilities with increasing age, both in the visual and auditory modalities. In the auditory domain, it is not clear whether this age-related decline is due to the age-related decrease in hearing sensitivity to relevant acoustic information, such as pitch-based cues, or to changes in later-stage cognitive processing of this information. In this study, to provide a baseline performance measure as a function of age in listeners without a CI, we investigated the effect of age on sensitivity to F0 and VTL cues by measuring just-noticeable differences (JNDs) via an adaptive 3I-3AFC paradigm in listeners across the adult lifespan. Furthermore, we assessed the effect of age on sensitivity index d-prime by measuring recognition of three core emotions (happiness, anger, sadness) in a 1I-3AFC paradigm.

Here we present data from 26 adults between 24 and 70 years of age with self-reported normal hearing. Data was collected through a remote testing procedure on a web-based platform. Our results show that sensitivity to F0 differences was significantly affected by age, as shown by larger JNDs with increasing age. This study was also the first study to directly assess the effects of age on VTL JNDs and our data show that VTL sensitivity was only marginally affected by age. There was a significant main effect of age on d-prime values of vocal emotion recognition. Taken together, these results suggest that general aging can affect both early-stage processing of acoustic voice cues and later-stage cognitive processing of emotional speech. These general aging effects could contribute to some extent to the performance of CI users as well during vocal emotion perception and in tasks involving F0 discrimination, while VTL discrimination may not be affected by age as much. Given that VTL perception seems more difficult in CI users than F0 perception, these results imply that difficulties in VTL perception seem more likely due to the signal transmission of CIs than to general age effects.

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1428: EFFECT OF PULSE RATE ON SPEECH PERCEPTION AND TEMPORAL PROCESSING OF COCHLEAR IMPLANT USERS

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In most cochlear implant (CI) coding strategies, acoustic information is encoded by modulating amplitude of electrical pulses delivered to implant electrodes. The rate at which electric pulses are delivered can be viewed as the update rate for amplitude modulations. Higher carrier rates permit encoding of more rapid acoustic envelope modulations, and might be beneficial for transmission of brief or fast-changing phonetic cues. However, there is evidence that high carrier pulse rates may be detrimental to the ability to detect amplitude changes (e.g. Azadpour et al. 2018). This study systematically investigates the effects of pulse rate on speech perception and temporal processing performance of CI users. A broad range of pulse rates was tested, which could provide a clearer understanding of the maximum and minimum pulse rates that should be utilized in clinical coding strategies without considerably impairing speech perception.

We evaluated the effect of pulse rate on speech perception by measuring consonant identification in a closed-set vowel-consonant-vowel identification task. The effect of pulse rate on temporal processing was evaluated by measuring detection thresholds for 25 Hz amplitude modulations applied to wide-band noise stimuli. Stimuli were processed with single- channel and ACE strategies on a PC, and were streamed to the implant via the CCI-Mobile platform. Single-channel strategies presented the overall envelope of the signal to an electrode in the middle of the electrode array. ACE strategies used the active electrodes in the subjects' clinical device. Number of maxima was typically 6. The tested pulse rates were 125, 250, 500, 1000, and 2000 pps/channel (pulses-per-second per channel). 4000 pps/channel was also included for the single-channel strategy. Threshold and comfort levels were obtained for each electrode and at each rate.

The results confirm inter-subject variability in the way performance in speech perception and modulation detection tasks changes with pulse rate. Overall, the highest performance in both tasks was achieved with the range of pulse rates between 250 and 2000 pps/channel. In most cases, performance dropped in both tasks as pulse rate was either increased or decreased beyond this range. Consonant recognition scores were lower with the single-channel strategies than with ACE, as expected. In contrast, modulation detection performance was better with the single-channel strategies. This interesting observation suggests that the inherent fluctuations in the narrow-band output of ACE strategy channels may distort representation of amplitude modulation cues in the stimuli.

The results so far do not show strong correlations between speech perception and modulation detection performance. Generally, these results support the hypothesis that excessively high or low stimulation rates could disrupt perception of speech temporal cues.

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1431: TOWARD BETTER UNDERSTANDING OF THE RELATIONSHIP BETWEEN FOCUSED THRESHOLDS AND VOWEL IDENTIFICATION IN LISTENERS WITH COCHLEAR IMPLANTS

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Introduction. Despite successful performance of cochlear implant listeners (CI) in understanding speech in quiet, speech recognition is still highly variable among individual CI listeners and performance is poor in the presence of noise and in music appreciation. The quality of electrode-neuron interfaces (ENIs), the quality by which electrodes stimulate their nearby auditory nerves, is an important factor that may contribute to these challenges for CI listeners. Single-channel auditory detection thresholds in response to spatially-focused electrical fields (focused threshold) are shown to be sensitive to some aspects of ENIs including neural health. The thresholds will be higher for electrodes near dead regions. Prior studies from our lab have demonstrated that higher average focused thresholds correspond to poorer speech recognition. However, the relation of focused thresholds of individual electrodes and errors in vowel identification is not well studied. Understanding this relationship at the individual electrode level will allow us to examine whether identification of specific vowels can be improved by applying dynamic focusing or channel deactivation on a subset of electrodes with poor ENIs.

Method. Fifteen children (11 bilaterally implanted) and twenty one adults (5 bilaterally implanted) with cochlear implants participated in this study. Mean age of implantation was about 5 years for children and 53 years for adults. Twenty six ears were tested for each age group (children and adults). All participants received Advanced Bionics HiRes 90k device. Single-channel focused thresholds were measured for electrodes 2-15 using the sweep threshold procedure (Bierer et al., 2015). Highly focused thresholds were measured using the steered quadrupolar (sQP) configuration with a focused coefficient of $\sigma = 0.9$. Medial vowel identification was measured in the /hVd/ context for ten vowels, presented at 60 dB SPL in two conditions, quiet and noise. The background noise was 4-talker babble presented at a +10 dB signal-to-noise-ratio (SNR). A threshold-vowel identification correlation (TVIC) profile was constructed by calculating the correlations between focused threshold of individual electrodes and errors in identification of each vowel.

Results. The TVIC profiles in quiet and noise showed that the relationship between focused thresholds and errors in vowel identification varied across electrodes and for different vowels. A subset of electrodes in the apical region (E2-E5) and basal regions (E11-E13) were more strongly correlated with errors in vowel identification in quiet, although the patterns of predictions were not consistent across vowels. Focused thresholds of individual electrodes were less predictive of errors in vowel identification in the presence of noise. The overall patterns of association between focused thresholds in individual channels and errors in identification of each vowel suggest that errors in vowel identification are influenced by high focused thresholds in frequency ranges that are not solely limited to the first and second formant frequencies. The subset of channels for which focused threshold was a significant predictor of error in vowel identification was dependent on the vowel, suggesting that poor ENIs for individual electrodes, as reflected by focused thresholds, differentially impact identification of different vowels. This suggests that developing an optimal programming strategy for speech perception improvement based on current focusing or channel deactivation requires consideration of the subset of electrodes with poor ENIs. Results showed that identification of vowels was less influenced by variation in focused thresholds of individual electrodes in children compared to adults CI listeners, suggesting the need for tailoring the programs differently for children and adults.

Conclusions. The patterns of association between focused threshold and vowel identification are variable for individual vowels and electrodes, demonstrating the complexities of the connection between site-specific measures of the quality of ENIs such as individual focused thresholds and patterns of errors in vowel identification.

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1451: IMPACT OF A SPATIAL POST-FILTER ALGORITHM ON SPEECH PERCEPTION AND LISTENING EFFORT IN COCHLEAR IMPLANT USERS IN COMPLEX LISTENING ENVIRONMENTS

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Introduction: Speech perception in noise is still one of the most challenging tasks for cochlear implant (CI) users. The use of fixed and adaptive beamformers are established methods to improve signal-to-noise ratio in such listening conditions. However, the beneficial effect of beamformers in reverberation is substantially diminished. The aim of the present study was to compare speech perception in noise and listening effort in CI users for different settings of directional sensitivity in free-field and reverberation.

Method: 19 unilateral (UNI) and 14 bilateral (BIL) CI users took part in the study. All CI users had a listening experience with CI of at least 9 months and used Cochlear CP1000 sound processors. Speech reception thresholds (SRTs) in situations with multiple temporally modulated noise sources were assessed with the German matrix test in free-field and reverberation. A sound reproduction setup comprising 128 loudspeakers was used for simulation of room acoustics in a classroom of typical size. Furthermore, listening effort was estimated using an adaptive category scaling procedure (ACALES). Measurements were conducted using the standard microphone directionality (sub-cardioid) and compared with (1) an adaptive beamformer and (2) spatial post-filter algorithm “ForwardFocus”.

Results: SRTs in free-field using either adaptive beamformer or spatial post-filter were significantly better than with sub-cardioid directivity in both subject groups. Lowest SRTs were found in the speech processor setting with activated spatial post-filter. Highest benefit of spatial pre-processing was found in the unilateral group (6.1 dB SRT improvement compared to sub-cardioid microphone). Individual CI subjects achieved an SRT improvement up to 10 dB with spatial post-filter compared to standard microphone setting. Listening effort was rated as reduced for adaptive beamformer (UNI: 1 category, BIL: 1-1.5 categories and spatial post-filter (UNI: 2-3 categories, BIL: 3 categories).
In reverberation no SRT improvements by using an adaptive beamformer were found in both subject groups. A slight but significant improvement (UNI: 2 dB, BIL: 1.3 dB) was found with spatial post-filter setting compared with sub-cardioid microphone. Improvements in listening effort were only one category or less.

Conclusion: In the present study, a spatial post-filter proved to be an effective application for SRT improvement in noisy conditions in free-field in different CI groups. However, this benefit was strongly reduced in the presence of reverberation.

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1475: A COMPARISON OF OFFLINE MEASURES FOR INTELLIGIBILITY ASSESSMENT OF TIME-FREQUENCY MASKED REVERBERANT CI-PROCESSED SPEECH

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Cochlear implant (CI) users can experience large degradations in speech intelligibility in reverberant environments (Kressner et al. 2018). When sound reflects from surfaces in an enclosure, reverberant reflections arrive at the listener at the same time as the direct speech signal. Modern CI speech processing algorithms transform the speech envelope activity within frequency bands into a pattern of stimulus pulses delivered across electrode channels. When the simultaneous arrival of reverberant reflections degrades the speech envelope, CI speech intelligibility worsens. Speech enhancement algorithms can be developed to remove reverberant artifacts, restoring speech envelope structure and recovering speech intelligibility for CI users in reverberation (Hazrati et al. 2013; Desmond, 2014).

One such speech enhancement approach, time-frequency masking, identifies speech-dominant time-frequency (T-F) units of a signal to retain based on a function of the signal and interference energies within the local speech envelope. By adjusting parameters of the masking function, the tolerance for reverberant distortions within the CI stimulus is adjusted, resulting in ideal masks with varying levels of reverberant signal retention. To compute an ideal mask, a priori knowledge of clean signal and interference energies is required. When a priori information is unavailable, algorithms can be developed to estimate T-F masks from the reverberant signal using an ideal mask as an estimation objective (Hazrati et al. 2013). As the estimated mask approaches the ideal mask, the intelligibility of the mitigated signal will approach the intelligibility of the signal mitigated with the ideal mask. Improvements in mask estimation may not confer similar levels of improvements in speech understanding because T-F components of speech are not equivalently important for speech understanding. In order to assess mask estimation efficacy, the intelligibility of the whole mitigated speech utterance must be considered.

The intelligibility of enhanced speech is typically assessed using online speech recognition testing of human subjects in which each speech utterance is assigned a global score based on the participant's recall of the speech content. While online testing remains the gold standard for measuring intelligibility, online testing is costly and time-intensive, making it poorly suited for fine-tuning parameters during algorithm development. Alternatively, offline measures of speech intelligibility can provide a practical option for assessing the performance of a speech enhancement algorithm during development without the need for testing in human subjects. Offline measures assess speech intelligibility by leveraging signal characteristics consistent with highly intelligible speech. Several offline measures target the intelligibility of CI-processed speech signals in noise or reverberation (Yousefian et al. 2012; Chen et al. 2013; Santos et al. 2013). Unfortunately, offline measures can fail to predict trends in T-F masked speech, particularly when differences between masks are not uniformly distributed (Kressner et al. 2016). Thus, it is important to assess the performance of offline measures on T-F masked speech containing representative and realistic changes in important speech content across conditions.

This work extends previous analyses of offline measures (Santos et al. 2013; Falk et al. 2015) to predict the performance of T-F masked reverberant speech after CI processing by including the most widely adopted offline measures used in the literature and introducing new speech intelligibility data for validation. To generate a broad range of speech intelligibility scores, we evaluated the intelligibility observed in normal-hearing subjects when tested with vocoded speech enhanced with T-F masks generated across a range of reverberant distortion tolerances. The correlation of offline measure scores to online intelligibility results will be reported, indicating offline measures that leverage speech features relevant to the intelligibility of reverberant CI-processed speech enhanced with T-F masking.

1481: CHILDREN WITH COCHLEAR IMPLANTS USE SEMANTIC PREDICTION TO FACILITATE SPOKEN WORD RECOGNITION

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Children with cochlear implants (CIs) are more likely to have difficulty with spoken language than their peers with normal hearing (NH). Recent language processing literature suggests these challenges in spoken language comprehension may be linked to slower spoken word recognition. Children with CIs recognize words less efficiently than children with NH, but it is unclear how these inefficiencies impact higher-level language processing. There are mixed findings in whether children with CIs utilize semantic cues to facilitate spoken word recognition. This is an important question to clarify because use of top-down language knowledge could help children to compensate for uncertainties in the speech signal they are receiving via the CI. This study investigates semantic prediction during sentence comprehension by 24 5- to-10-year-old children with CIs, comparing performance to both an age-matched group and vocabulary-matched group of children with NH. Children listened to sentences with either a predictive or neutral verb (The brother draws/gets the small picture) while eye gaze was recorded to images on a screen (target [picture], cohort [pickle], unrelated distractors [cookies, costume]). Results demonstrate that children with CIs use semantic cues to facilitate recognition of upcoming words, but do so less efficiently than children with NH, even when matched for vocabulary ability. Children with CIs experience challenges in spoken language processing above and beyond limitations from delayed vocabulary development. However, those children with CIs who have better vocabulary skills also demonstrate more efficient use of lexical-semantic cues. Top-down prediction strategies may be a helpful tool in compensating for uncertainty in the acoustic signal.

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1484: FEW COCHLEAR-IMPLANT LISTENERS EMPLOY SPEECH REPAIR STRATEGIES IN NOISY LISTENING SCENARIOS

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Speech repair strategies allow normal-hearing listeners to perceptually restore noise-interrupted sentences, which is a critical communication skill in noisy real-world listening environments like cafeterias or classrooms. We initially aimed to increase speech repair use among cochlear-implant (CI) listeners, building on prior work in the field demonstrating that CI listeners could repair speech containing brief, infrequent noise interruptions. However, several of our experiments failed to detect speech repair use in CI listeners. Our most recent work thus aimed to replicate the prior work in the field, while also assessing how signal properties like duration, frequency, and level of noise interruptions could impact CI listeners' speech repair use.

In the first experiment, we conducted a close replication of the only prior study (Bhargava, Gaudrain, and Başkent, 2014) on perceptual restoration of speech in CI listeners. Sentences interrupted with either periodic noise bursts or periodic silent gaps were presented to CI listeners, who repeated the sentence verbally. Higher sentence understanding accuracy with noise-burst interrupted speech compared to silent-gap interrupted speech is considered indicative of successful perceptual restoration. Despite using the procedure, training regimen, and many of the same signal parameters described in the original study, speech repair was not observed in our sample of CI listeners.

In a second experiment, we performed an exploratory survey which measured whether combinations of various duty cycles (affecting the duration of interruptions) and interruption rates (affecting the frequency of interruptions) could provide opportunities for CI listeners to use speech repair. For example, we expected that infrequent interruptions could allow CI listeners to utilize more of the speech envelope, which would increase restoration. However, no speech repair was observed in any condition.

In a third experiment, we measured whether CI compression algorithms, possibly activated by the loud noise interruptions in our stimuli, affected performance in the noise-interrupted sentence conditions. CI listeners completed the speech repair experiment at two signal levels: first, below the automatic gain control knee-point (during which noise bursts and speech stimuli were both presented at levels below the point where CI compression algorithms are engaged) and second, spanning this knee-point (during which noise bursts, but not speech stimuli, were presented at a level that should engage the compression algorithm). Regardless of compression activation, no speech repair was observed.

In summary, the majority of CI listeners tested did not demonstrate perceptual restoration. These findings are important for changing our perspective on how noisy sentences may be processed by CI listeners, and indicate that a lack of speech repair use may contribute to this population's often-reported difficulty understanding speech in noisy, real-world listening environments.

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1514: GENDER CATEGORIZATION BY EARLY-DEAFENED LATE-IMPLANTED DIFFERS FROM THAT OF TYPICAL COCHLEAR-IMPLANT USERS

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To be able to follow a conversation in a group of people, one of the key abilities to keep up with the story told, is to be able to differentiate between different talkers and therewith to identify different voices. Voice identification and gender categorization have been shown to be generally more difficult and different for cochlear implant (CI) users compared to normal hearing listeners. Two groups of CI users, early-deafened, late-implanted (EDLI) CI users and postlingually deafened and implanted, typical CI users, are compared for the perception of voice characteristics and the categorization of the gender of a talker. The deafness at an early age and the long period of auditory deprivation before implantation, might cause EDLI CI users to have an extra deficiency for voice identification. Eighteen EDLI CI users and eighteen post-lingually deafened control CI users were recruited. Two studies were conducted: 1) a study that compared the just-noticeable-differences for two voice characteristics: the fundamental frequency (F0), which is related to the glottal pulse rate of the vocal chords, and the vocal-tract length (VTL), which is related to the size of the speaker; 2) a study that compared the parametric vocal gender categorization as a function of F0 and VTL. The results of the first study showed an average F0 and VTL JNDs of 9.0 st and 9.7 st, respectively, for the EDLI CI users, in comparison to 7.9 st and 6.9 st for the control CI group. These differences were not significantly different between the two groups. The results of the second study showed a group effect, meaning that EDLI participants seemed biased towards male voices. Also, a significant difference for use of F0 and VTL cues was shown, meaning that EDLI participants relied less on F0, relative to VTL, than the control group. Even though the JND's were not significantly different between both groups a different categorization of gender was shown between the two groups of CI users. The explanation for our findings can be twofold: first, the EDLI group's lack of exposure to F0 and VTL differences at an earlier age may have affected their ability to associate those differences with gender. Second, the results suggest that the association between F0 and gender in the postlingually deafened CI users, postlingually deafened CI users relied on F0 for gender categorization, might originate from acoustic exposure preceding deafness. In other words, our results indicate that the percept yielded by F0 in the postlingually deafened group is still similar enough to the acoustic analog.

Evoked Potentials and Imaging – Invited and Featured Talks and Posters

Invited Recorded Talk:
1551: SYNCHROTRON IMAGING OF THE INNER EAR

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Since synchrotron radiation phase-contrast imaging (SR-PCI) was first performed on intact, unstained human cochleae, a tremendous amount of anatomic knowledge has been extracted from the detailed images. In particular, visualization of the basilar membrane, spiral ganglion, and peripheral axons in three dimensions has allowed the creation of detailed tonotopic maps of the cochlea. This talk will summarize the first patient-specific tonotopic mapping formula developed using these images. Finally, future applications using artificial intelligence analysis will also be discussed.

Featured Recorded Talk:

1308: FUNDAMENTAL FREQUENCY PROCESSING IN MANDARIN-SPEAKING CHILDREN WITH COCHLEAR IMPLANTS AS REVEALED BY THE PEAK LATENCY OF POSITIVE MISMATCH RESPONSE (P-MMR)

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Purpose: Fundamental frequency (F0) serves as the primary acoustic cue for Mandarin tone perception. Recent studies on the use of F0 contours for Mandarin tone perception suggest that F0 contours may be differently processed between Mandarin-speaking normal-hearing (NH) children and children with cochlear implants. The aim of the current study was to explore this issue from the perspective of electrophysiology.

Method: Positive mismatch responses (p-MMR) to the change of two acoustic dimensions of F0, i.e., F0 contour and F0 level change, were respectively recorded in Mandarin-speaking kindergarten-aged children with CIs and their age-matched NH peers. Mean amplitude and peak latency of p-MMRs to F0 contour/F0 level change were compared between these two groups of children.

Results: The mean amplitude of p-MMR to either F0 contour or F0 level change did not show any significant differences between children with CIs and NH children. While the peak latency of p-MMR to F0 contour change was significantly longer than that to F0 level change in NH children, opposite pattern was seen in children with CIs. Moreover, p-MMR to F0 contour change in children with CIs exhibited the shortest peak latency, which was significantly shorter than those to F0 contour and F0 level change in NH children. No significant correlation was found between CI-related demographic factors (e.g., age at implantation, duration of CI use) and amplitude/peak latency of p-MMRs to F0 contour/F0 level change.

Conclusions: Consistent with the previously reported behavioral findings, the discrepant neural responses to F0 change between children with CIs and NH children in this study suggest different F0 processing in these two groups, which may partially explain the unsatisfactory speech perception outcomes with new speech processing strategies among CI users speaking tonal languages.

1323: USING STIMULI OF HIGH-RATE MULTI-PULSE TRAINS TO ESTIMATE CLINICAL THRESHOLDS IN COCHLEAR IMPLANT USERS

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Introduction
Due to the limited dynamic range available in electric hearing, it is crucial that hearing thresholds (THRs) of cochlear implants (CIs) are adjusted properly. The THR determination is a routine clinical procedure for CI users who can give feedback, it becomes hard if the implantee is unable to cooperate, e.g. infants. In such situations, objective measures such as electrically evoked auditory brainstem responses (eABRs) could be used for THR estimation. It is known that THRs depend on the duration of the stimuli as well as on the stimulation rate. For low-rate stimulation, there is a strong correlation between behavioural THRs and eABR THRs. At high rates (e.g. rates used in clinics), however, the correlation is weaker due to the missing effects of temporal integration. We therefore employed trains of multi-pulse (MP) bursts to at least partially incorporate the integration induced at clinical rates.

Material & Methods
Thirteen ears from nine subjects (three males) with MEDEL CIs were measured. Single symmetric biphasic pulses with phase length of 45 µs were concatenated to construct 2-, 4-, 8-, and 16-pulses. Stimuli were delivered at a burst rate of 10000 pulses-per-second (pps). Also clinical THRs in response to single-pulse trains at a rate of 1000 pps were measured. eABR wave eV amplitudes and their RMS values were used as features and their growth functions were fitted and extrapolated to estimate eABR THRs at MP conditions. Linear and exponential fitting functions (FFs) were used for extrapolation of growth functions.
Results

Growth functions of eABR wave eV amplitudes were generally monotonic and as expected, for higher stimulation amplitudes, they tended to saturate. We found that the estimated eABR THRs at 4-, 8-, and 16-pulses conditions were closer to the clinical THRs, when compared to single-pulse and 2-pulses. For different combinations of estimation features and fitting functions, absolute differences (median) between eABR THRs and clinical THRs were 48.6, 39.5, 25.9, and 30.3 µA, three of which occurred at 4-pulses conditions and one at 16-pulses condition. Analysis showed weak correlations between eABR THRs and clinical THRs (average Pearson correlation coefficients were 0.48 ± 0.24 (mean ± STD)).

Results of this study showed that, stimuli with extended duration are able to cover higher processing steps such as temporal integration and facilitation. This holds the capability of MP stimulation to improve the estimation of clinical THRs with objective measures such as eABRs.

1324: SPEEDCAP: A FAST METHOD TO ESTIMATE PATIENT-SPECIFIC PATTERNS OF NEURAL HEALTH AND CURRENT SPREAD USING ELECTRICALLY-EVOKED COMPOUND ACTION POTENTIALS

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Electrically-Evoked Compound Action-Potentials (ECAPs) can be recorded using cochlear implant (CI) electrodes and represent the synchronous response of the electrically-excited auditory-nerve. Various combinations of these ECAP measures from multiple electrodes have been used to shed light on cases of poor CI speech performance and to model patterns of neural activation, including estimation of neural health and spread of excitation. We use the Panoramic ECAP (PECAP) method, which provides patient-specific estimates of variation in neural health and current spread along the length of a CI array (Garcia et al, 2021). ECAPs can be measured easily in the clinic and in the operating theatre; they require no additional measurement equipment beyond the implant itself and clinical software. However, the measurement of ECAPs from multiple combinations of electrodes can be sufficiently time-consuming as to restrict their clinical usefulness. Here we propose a fast method, SpeedCAP, which optimises ECAP recordings by minimising some of the redundancies that can arise when multiple ECAPs are recorded.

ECAPs were recorded using the forward-masking artefact-cancellation technique for all combinations of masker and probe electrodes, presented at equal loudness levels. Participants were all users of CIs manufactured by Cochlear. ECAPs were recorded either using the clinical software (referred to hereafter as SlowCAP) or the SpeedCAP method. SlowCAP yielded a full matrix of ECAPs referred to as M0 (22 electrodes: 444 ECAPs). SpeedCAP was built on an assumption of symmetry across the diagonal of M0, and yielded half a matrix of ECAPs referred to as MS (22 electrodes: 253 ECAPs) from the same CI users and reduced the data collection time from 45 minutes to 8 minutes. We evaluate SpeedCAP by comparing the ECAP amplitudes in the unprocessed M0 and MS data, as well as their respective estimates of current spread and neural health from the PECAP Method. Preliminary results from the first 5 participants showed that agreement between ECAP amplitudes measured (in µV) with the two methods is very high, with an average error of only 3.3 ± 1.6% RMSE. Additionally, across-electrode, within-participant correlations between neural health estimates when M0 vs MS were submitted to the PECAP Method resulted in r-values of between 0.59 and 0.91 (all significant with $p < 0.005$). Correlations for current spread estimates were also all significant with r-values of between 0.51 and 0.99 (all $p < 0.0001$).

The improved efficiency of SpeedCAP provides time savings for efficient multiple-electrode recordings in routine clinical practice, even when slow stimulation rates are required to elicit ECAPs. The SpeedCAP data collection is sufficiently quick that it has already allowed us to record MS intra-operatively. Such measurements can thereafter be submitted to models such as the PECAP method to provide further, patient-specific insights into patient-specific patterns of neural activation that could be used to inform programming of clinical MAPs and/or address underlying causes of poor performance.

References: Garcia, C., Goehring, T., Cosentino, S., Turner, R. E., Deeks, J. M., Brochier, T., Rughooputh, T., Bance, M., Carlyon, R. P. (2020, August 27). The Panoramic ECAP Method: estimating patient-specific patterns of current spread and neural health in cochlear implant users. https://doi.org/10.31234/osf.io/xrz4f

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1331: MEASURING THE SIZE AND SELECTIVITY OF THE SUSTAINED PHASE-LOCKED NEURAL RESPONSE TO COCHLEAR-IMPLANT STIMULATION USING THE ALFIES METHOD

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An objective measure of the sustained neural response to cochlear-implant (CI) stimulation, and of the selectivity of that activation, could have multiple clinical and scientific applications. Unfortunately the neural response is invariably accompanied by a much-larger electrical artefact, thereby hampering its measurement. A common way to overcome this problem is to present pulses at rates much lower than those used clinically and to record the response in the gaps between pulses. We developed an alternative method, termed ALFIES (ALternating Frequency Interleaved Electrical Stimulation), which allows one to measure the sustained phase-locked neural response to electrical stimulation even at high pulse rates. The method involves interleaving two stimuli with frequencies F1 and F2 Hz and measuring a neural distortion response (NDR) at F2-F1 Hz. It relies on the fact that, because any one time-point contains only the F1 or F2 stimulus, the instantaneous nonlinearities typical of electrical artefacts should not produce distortion at this frequency. However if the stimulus is smoothed, such as by charge integration at the nerve membrane, subsequent (neural) nonlinearities can produce a component at F2-F1 Hz.

We first interleaved two 2322-pps pulse trains amplitude-modulated at F1 and F2 Hz (F2=1.5F1), respectively, and presented the mixture in monopolar (MP) mode to one electrode of a Cochlear CI for 300 sec. EEG responses were obtained using a BioSemi system and partitioned into 300 1-sec epochs. We found no evidence for an NDR when F2-F1 was between 90-120 Hz. However, when F2-F1 was ~ 40 Hz we observed a substantial NDR with a group delay of about 45 ms, consistent with a thalamic and/or cortical response. The NDR could be measured even from recording electrodes adjacent to the implant. We then measured the selectivity of this sustained response by presenting F1 and F2 to different CI electrodes and at different between-electrode distances. This revealed a broad tuning that, we argue, reflects the overlap between the excitation elicited by the two electrodes. We are presently investigating this explanation by measuring tuning using multi-electrode stimulation methods designed to reduce or enhance the selectivity of stimulation. Additionally, we are currently presenting interleaved 500-pps pulse trains to the same electrode in MP mode and measuring the dependence of the NDR amplitude on the gap between the pulses from the F1 and F2 pulse trains, in order to measure the time constant of the smoothing necessary for the generation of an NDR. We conclude that the ALFIES method provides a fast objective measure of the thalamic/cortical response to CI stimulation. Potential applications include improved interpretation of cases where a CI patient experiences poor speech perception, and evaluation in animal models of novel therapies designed to improve CI performance. ALFIES may also be applied to non-auditory domains where it is desired to measure the sustained neural response to electrical stimulation

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1342: TEMPORAL-PITCH CODING AS MEASURED WITH ACC, FFR AND PSYCHOPHYSICS IN NORMAL-HEARING HUMAN LISTENERS

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Cochlear implant (CI) users can hear the pitch of broadband periodic sounds, such as speech, thanks to the ability of the auditory system to derive pitch from purely temporal variations over time. As part of a Wellcome Trust collaborative award, we develop synergetic methods to measure temporal pitch coding (and its limitations) at different stages in the auditory pathway, in both normal-hearing and implanted humans and cats. Here, we evaluate a cortical electrophysiological measure of sensitivity to changes in temporal pitch (namely the ACC, Acoustic Change Complex) in normal-hearing humans. We compare the results both to psychophysical discrimination thresholds and to the frequency following response (FFR) using similar stimuli, as well as to analogous measures obtained in cats.

We generated acoustic pulse trains by summing harmonics of a given F0, and filtering these in one of two regions: a ‘HIGH’ region (3365-4755 Hz) and a ‘VHIGH’ region (7800-10800 Hz). For the ACC/FFR measurements (N = 13), we used a switching paradigm: the stimulus was presented continuously, and the pulse rate changed every second from a base rate (94, 188 or 280 pps) to a 36- or 66-% higher rate. We measured whether this change elicited an ACC at the scalp with a Biosemi EEG setup. Simultaneously, we measured the FFR to each pulse rate, making sure the stimulus polarity was flipped every time it switched back to the base rate. For the psychophysical measurements (N = ~10, data under collection), we used a 2-interval, 2-AFC, constant-stimulus procedure with four base rates (47, 94, 188 and 280 pps), five percent changes (2.5, 5, 10, 20 and 40 %) and the two frequency regions (HIGH vs VHIGH). The target interval included two continuous switches (base-rate to higher-rate then back to base-rate or vice-versa, i.e. starting with the higher-rate stimulus). There was no switch in the other, reference, interval.

EEG results showed strong FFRs, and small but significant ACCs in response to both the 36- and 66-% temporal-pitch changes, with larger ACCs for the 66-% change. The small size of these ACCs is consistent with the psychophysical results, which showed higher difference limens (10 to 25 %) than previously reported in the literature (~5%). This is likely because we used a continuous switching paradigm, while previous studies had a long silent gap between any switches in temporal pitch. Finally, while there was a strong effect of pulse rate on the brainstem-evoked FFR (decreasing amplitudes with increasing rate), this was not the case either for the ACC or for the psychophysical difference limens.

We discuss how these results compare to similar measurements in cats, and how they can inform the development of CI temporal pitch measures.

1345: IMPLICATIONS OF PHASE CHANGES IN EXTRACOCHLEAR ELECTROCOCHLEOGRAPHIC RECORDINGS DURING COCHLEAR IMPLANTATION

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Electrocochleography (ECochG) has recently been used to monitor changes in cochlear function during cochlear implantation. Amplitude changes in ECochG signals seem to be a promising marker for cochlear trauma during the insertion of cochlear implant (CI) electrode arrays and a potential predictor of postoperative hearing loss. It has been suggested that phase changes of the ECochG signal in addition to the amplitude changes could enhance our understanding of mechanisms underlying the changes of the ECochG signal. Therefore, the focus of this study is to explore implications of phase changes in extracochlear ECochG recordings during cochlear implantation in human CI recipients.

Extracochlear ECochG recordings of 69 ears in 68 subjects were included; 48 subjects received Cochlear®, 19 subjects received Advanced Bionics and 2 subjects received MED-EL devices. Extracochlear ECochG recordings were performed before (round window closed) and after insertion of the CI electrode array by placing a recording electrode on the promontory. ECochG responses to tone bursts at 250, 500, 750, and 1000 Hz (in total 210 recordings) with alternating starting phase were measured. To determine postoperative hearing loss, follow-up pure tone audiograms were conducted after 4 to 6 weeks and the pure-tone average (PTA) was calculated from the average of air-conduction threshold values at 250, 500, 750 and 1000 Hz on the operated side. The difference between pre- and post- implantation PTA was defined as the postoperative hearing loss.

The recorded ears were divided in two different groups; whether they had at least one recording with a phase change of ≥45°-89°or ≥90°. Phase changes of ≥45° were significantly more frequent at 250 and 500 Hz than at 750 and 1000 Hz. Such changes of signal latency can occur with or without amplitude changes. Neither a phase change of ≥45°-89° nor a phase change of ≥90° was strongly associated with an amplitude change. Phase changes of ≥90° with or without amplitude changes were associated with a larger postoperative hearing loss and could be used as a predictor for cochlear trauma or changes of inner ear mechanics relevant for the postoperative hearing outcome.

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1374: ARE CORTICAL ACTIVATION PATTERNS TO AUDITORY-ONLY AND VISUAL-ONLY SPEECH AS REVEALED BY FNIRS RELATED TO SPEECH UNDERSTANDING SCORES IMMEDIATELY FOLLOWING IMPLANT SWITCH-ON?

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The large variability in speech understanding scores obtained by adult cochlear implant (CI) users remains a challenge. Recent brain imaging research suggests that plastic changes in the cortex as a result of auditory deprivation play a crucial role in CI outcomes. Typically, cross-modal activation can be observed following a period of auditory deprivation, in which the auditory cortex will activate in response to visual input. It remains unclear, however, to what extend the presence of cross-modal activity impacts speech understanding outcomes in CI users. This study used functional near-infrared spectroscopy (fNIRS) in adult CI users to determine the relationship between cortical activation patterns elicited by auditory-only and visual-only connected speech signals with speech understanding scores immediately following implant switch-on.

Auditory- and visual-evoked activation patterns were measured via fNIRS in the left and right auditory cortices and the visual cortex in adult Nucleus CI users between 3 hours and 5 days following implant switch-on. The experimental stimulus consisted of a continuous speech signal segmented into 12.5s blocks and was presented in either an auditory-only or visual-only condition. Speech understanding scores for CNC words in quiet and BKB sentences in noise were evaluated at the same visit.

Preliminary results showed activation in the contralateral auditory cortex (contralateral to the implanted ear) in response to auditory-only speech stimuli. Responses to visual-only speech were more variable, with two out of three participants showing visual-evoked activation in the visual cortex (intra-modal activation) and one participant showing visual-evoked activation in the auditory cortex (cross-modal activation). These cortical activation patterns appear to be related to participants' duration of deafness rather than their initial post-implantation speech understanding scores, as all participants achieved relatively excellent scores immediately following implant switch-on. The participant with the longest duration of deafness prior to implantation showed visual-evoked cross-modal activity the auditory cortex.

These results suggest that cortical activation patterns for auditory-only and visual-only speech following implantation may be related to individual differences in hearing history (e.g., duration of deafness) and potentially to individual differences in speech understanding outcomes.

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1392: PREDICTING COCHLEAR IMPLANT PERFORMANCE: CONSIDERING THE TEMPORAL FIRING PROPERTIES OF AUDITORY NERVE FIBERS UNDERLYING HUMAN ECAPS

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Background: Ways to objectively assess the performance of cochlear implant (CI) recipients has been the subject of many studies, including ones using electrically evoked compound action potentials (eCAPs). These eCAP-based studies have focused on the amplitude information of the response and have not taken the temporal firing properties of excited auditory nerve fibers (ANFs) into account. Using a deconvolution method and a unitary response, the eCAP can be mathematically unraveled into the compound discharge latency distribution (CDLD). The CDLD reflects both the number of fibers and the temporal firing behavior of excited ANFs (Dong et al., Hear Res 2020; Dong et al. MethodsX 2021).

Objective: This study was designed to determine the extent to which speech perception in CI recipients can be predicted by the temporal firing properties underlying the recorded eCAPs as quantitatively analyzed in the CDLD.

Method: In this retrospective study, monosyllabic word scores and the intra-operative eCAP amplitude growth functions were collected from 134 postlingually deaf adult patients implanted with the Advanced Bionics HiRes 90K device. We extracted the CDLD from each recorded eCAP waveform using deconvolution. To reduce the parameter space and guarantee positivity the shape of the CDLD function was predefined to consist of two Gaussian components. These components reflected the sum of spiking events over time of individual excited ANFs. Each of the two Gaussians in the CDLD was described by three parameters, namely the amplitude, the firing latency (the average latency of each component of the CDLD), and the variance of latencies (an indication of the synchronicity of excited ANFs). The area under the CDLD (AUCD) was indicative of the total number of excited ANFs over time. Associations between speech perception and each of these CDLD parameters were investigated using linear mixed modeling.

Results: Speech perception of CI recipients was significantly associated with the peak amplitudes of the two components in CDLDs ($p=0.003$; $p = 0.01$ respectively) and AUCD ($p=0.005$) but not with the CDLD latencies ($p=0.2$; $p=0.82$ respectively). In addition, speech perception was significantly associated with the variance of latencies of the early component in CDLDs ($p=0.01$), but not with the latency variance of the late component ($p=0.06$). We found that better speech performance was significantly associated with a larger number and a greater degree of synchronicity of excited ANFs.

Conclusion: The results demonstrated that the number and the temporal firing properties of excited ANFs revealed by CDLDs are indicative of speech perception in CI recipients after implantation. We conclude that CDLDs can provide a clinical predictor of auditory nerve fiber survival and postoperative speech perception performance. Thus, it is worthwhile integrating the CDLD into eCAP measures in future clinical practice.

1421: EFFECT OF ADVANCED AGE ON NEURAL ADAPTATION RECOVERY IN COCHLEAR IMPLANT USERS

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Background: Fast recovery from neural adaptation of the auditory nerve (AN) has been proposed to be important for enhancing acoustic onsets in the speech waveform (Delgutte 1997). Slow recovery from neural adaption has been proposed to contribute to poor speech perception in some cochlear implant (CI) users (Nelson & Donaldson 2002). To date, recovery from neural adaptation at the level of the AN has not been systematically characterized in human CI users. In addition, the effect of advanced age on neural adaptation recovery has not yet been determined. This study was designed to address these two knowledge gaps. The first aim of the study was to comprehensively characterize adaptation recovery functions (ARFs) measured at multiple pulse rates and electrode locations in postlingually deafened adult CI users. The second aim was to investigate the association between age at testing and the amount and the speed of neural adaptation recovery in these patients. This study tested the hypothesis that advanced age was associated with less and slower recovery from neural adaptation at the level of the AN.

Methods: This study included 25 postlingually deafened adult CI users. The age at testing ranged from 24.83 to 83.21 years (mean: 61.17 yrs, std: 15.93 yrs). All participants had a Cochlear™ Nucleus® device with a full electrode array insertion in the test ear. The stimuli were 100-ms pulse trains with pulse rates of 500, 900, 1800 and 2400 pulses per second (pps) per channel. The masker-probe-intervals (MPIs) tested in this study included 2, 4, 8, 16, 32, 64, 128 and 256 ms. For each participant, electrically evoked compound action potential (eCAPs) were measured at 3-4 electrode locations across the electrode array using a modified forward-masking technique. Amplitudes of the pulse train eCAPs were normalized to the amplitude of the eCAP in response to a single pulse. The ARF was obtained by plotting normalized eCAP amplitudes as a function of MPI on a logarithmic scale. Each eCAP ARF was characterized with a qualitative description of the function shape and a quantitative description of the time constants of recovery. The amount of adaptation recovery was quantified by the ratio between the eCAP amplitude measured at the MPI of 256 ms and the amplitude of the eCAP evoked by the single pulse. The speed of adaptation recovery was estimated using a mathematical model with up to three exponential components. The correlations between age at testing and characteristics of the eCAP ARF (i.e., amount and speed of recovery) were assessed with one-tailed, Spearman's rank correlational analyses.

Results: There were 345 ARFs measured in this study. Results of preliminary data analyses showed three ARF types/shapes observed in this study. Type I functions were dominated by one increasing phase over the time course of 256 ms. Type II functions consisted of two phases: a decreasing phase within the first 10 ms, followed by an increasing phase within a time window of around 10-256 ms. Type III functions consisted of three phases occurring in sequence: an increasing phase occurring within the first 5 ms, a decreasing phase within a time window of around 5-10 ms, and a second increasing phase within a time window of around 10-256 ms. The number of functions classified as Type 1, Type 2 and Type 3 were 53 (15.37%), 39 (11.30%) and 253 (73.33%), respectively. For each study participant, the function type varied across electrode locations and pulse rates. There was no significant correlation between age at testing and the amount or the speed of recovery from neural adaptation at any pulse rate tested ($p>0.05$).

Conclusions: Characteristics of ARFs measured in human CI users demonstrate substantial variations. Advanced age is not a robust factor for the amount or the speed of recovery from neural adaptation at the level of the AN in CI users.

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1469: THE EFFECT OF AGEING ON CERVICAL VESTIBULAR EVOKED MYOGENIC POTENTIALS (CVEMPS): A RETROSPECTIVE REVIEW

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Objectives/Hypothesis
We aimed to determine the effect of ageing on the cervical vestibular evoked myogenic potential (cVEMP). The cVEMP assesses the integrity of the saccule and inferior vestibular nerve; these structures may be subject to similar dysfunction that occurs in the cochlea in individuals with hearing loss and could incur further insult from cochlear implantation. Measuring vestibular responses before CI is important to assess saccular function prior to surgery to disentangle the presence of vestibular deficits that are concurrent with deafness from the vestibular risks of implantation. cVEMP measures are dependent upon muscle contraction strength but both contraction strength as well as vestibular function could deteriorate with age. We hypothesized that: 1) the EMG contraction strength in the sternocleidomastoid (SCM) weakens with age into older adulthood, resulting in reduced cVEMP amplitude, and 2) cVEMPS corrected for contraction strength decrease in amplitude with age, reflecting declining vestibular function.

Methods
Twenty-four individuals with normal hearing participated in this retrospective study. cVEMP data from two separate cohort studies were used: 1) adolescents and young adults (11 male, 4 female); 8 young adults (mean(SD) age 23.06 (3.10) years), and 7 children (mean(SD) age 14.37 (0.45) years); total mean (SD) age 18.65(7.92) years, range 8-29 years, and 2) older adults (4 male, 5 female); mean(SD) age 68(2.40) years, range 65-72 years. Contraction strength was measured as the rectified EMG amplitude in the prestimulus epoch from -20 to 0 msec over the recording time. cVEMP amplitude was measured between expected peak P1 and N1 latencies.

Results
Stable contraction strength of the SCM was found in all three groups from the first to second half of recording; contraction strength increased from adolescence into young adulthood ($t(38.87) = 2.07$, $p=0.04$) but decreased in older adults ($t(41.90) = -2.53$, $p=0.02$). Raw cVEMP amplitude remained stable from adolescence to young adulthood ($t(38.38)=0.006$, $p=0.10$) but decreased in older adults ($t(43.65)= -2.90$, $p=0.006$). When normalized by contraction strength, cVEMP amplitudes decreased from adolescence to young adulthood ($t(36.60)=-2.92$, $p=0.006$) and then remained stable into older adulthood ($t(40.84)=-1.22$, $p=0.23$).

Conclusion/Significance
The findings suggest that cVEMP amplitudes in older adults may reflect declines in contraction strength that occur with ageing. Normalizing cVEMP by contraction strength is important when considering vestibular function as a criterion for cochlear implant candidacy in both children and adults.

1489: INTRAOPERATIVE MONITORING DURING COCHLEAR IMPLANTATION USING SIMULTANEOUS INTRA- AND EXTRACOCHLEAR ELECTROCOCHLEOGRAPHY

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The objective to preserve residual hearing following cochlear implantation has recently led to the use of ECochG as an intra-operative monitoring tool. Although various studies investigated the relationship between intra-operative ECochG measurements and surgical outcomes in recent years, the limited interpretability of ECochG response changes leads to conflicting study results. Especially in intracochlear ECochG recordings, interpretation of signal changes with respect to cochlear trauma is difficult due to the movement of the recording electrode with respect to the different signal generators. In this study, we compared ECochG signals recorded simultaneously from intracochlear locations through the cochlear implants most apical electrode and from a fixed extracochlear location. We measured ECochG responses to 500 Hz tone bursts with alternating starting phases during cochlear implant insertions in nine human cochlear implant recipients. Our results show that an amplitude decrease with associated near 180-degree phase shift and harmonic distortions in the intracochlear difference curve during the first half of insertion was not accompanied by a decrease in the extracochlear difference curve's amplitude (n = 1). Late amplitude decreases in intracochlear difference curves (near full insertion, n = 2) did correspond to extracochlear amplitude decreases. These findings suggest that comparison of ECochG signals recorded simultaneously from intracochlear locations and from a fixed extracochlear location can potentially allow a differentiation between traumatic and atraumatic signal changes in intracochlear recordings.

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1498: NAUTILUS: A CLINICAL TOOL FOR THE SEGMENTATION OF INTRA-COCHLEAR STRUCTURES AND RELATED APPLICATIONS - ACCURACY AND ROBUSTNESS

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The ability to reliably identify the cochlea and its inner structures and to detect and represent the electrode of a cochlear implant within these structures from conventional CT scans is key for enabling a safer and more individualized CI therapy. In this paper, we introduce Nautilus, a web-based imaging pipeline that allows the accurate and robust segmentation of the Scala Tympani, Scala Vestibuli, and Basilar Membrane from pre-operative CT or cone-beam CT scans using a hybrid approach coupling of deep-learning segmentation techniques and a Bayesian joint appearance-and-shape inference model (Deep-JASMIN). Nautilus automatically detects and reconstructs the Oticon Medical Evo electrode from post-operative images and registers it within the corresponding pre-operative cochlear segmentations. A wide panel of cochlear metrics and measures relative to electrode placement is computed from the processed images and made available to Nautilus users involved in basic or clinical research projects. These include but are not limited to A, B, measured cochlear duct lengths along various trajectories within the ST, the cross-sectional height and widths of ST and SV along the cochlear spiral, and the normalized Greenwood frequency for each electrode contact in relation to the estimated location of the nearest Spiral Ganglion

The accuracy of the pre-operative detection of ST, SV, and BM is calculated using a validation set composed of nine manually annotated micro-CT images. Local DICE scores for ST and SV are presented for various angular bins along the cochlear spiral with scores consistently neighboring 0.8 in the first two cochlear turns. Accuracy on the prediction of BM position is presented as a signed distance from the inferred isosurface representing BM to the ground-truth isosurface and reveals median deviations in the order of 0.1mm.

We discuss robustness of the pipeline with respect to varying resolution and contrast of images used in clinical settings. We underline the robust processing of both pre-operative and post-operative modules of Nautilus by examining a qualitative user-rating of the segmented cochlear structures and electrode contact detection for more than 160 images quantified in contrast, resolution, and overall quality. Finally, we present our strategy for transparency on detection uncertainty and failure and put our results in the perspective of future needs for the reliable detection and processing of abnormal cochlear anatomies and ossifications.

The current accuracy and robustness of the Nautilus tool provide legitimate grounds for envisaging advanced CI therapy, from the specification of a specific electrode insertion depth and the prediction of possible insertion difficulties during surgical planning to an anatomy- or anatomo-physiologically-tuned baseline frequency mapping at activation and accompanying gains in clinical outcomes these features may make possible.

1512: A DIAGNOSTIC ALGORITHM USING TRANSIMPEDANCES TO CHECK THE POSITION OF COCHLEAR IMPLANT ELECTRODE ARRAYS

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While radiographic examination is a well-established technique in some clinics to ensure proper surgical placement of cochlear implant electrode arrays, exposure to radiation should be minimized, especially in pediatric patients, and access to imaging equipment can limit the immediacy of corrective actions. In this study we measured 22x22 transimpedance matrices (TIMs) with the Slim Modiolar electrode array (CI532/CI632, Cochlear Ltd) implanted into human temporal bone samples. In a subset of insertions, a tip fold-over of the electrode array was purposefully introduced by fixing a thin wire attached to the tip of the electrode to limit its maximum insertion depth while advancing the base of the array.

Several algorithms were developed to automatically classify normal from folded insertions and determine the location of the fold. Given the low incidence of tip fold-overs, both high sensitivity (true positives) and high specificity (true negatives) were required. A first training dataset of TIM measures was collected immediately after array insertion for early testing and comparison of the algorithms. A candidate algorithm based on gradient vectors of the TIM had the best overall accuracy, was further tuned for the desired balance between sensitivity and specificity, and was selected for further validation.

After the candidate algorithm was fixed, independent validation datasets of normal (n=31) and folded (n=35) electrode array positions were created with new insertions in temporal bones. Validation of the final algorithm demonstrated high sensitivity (35/35) and specificity (29/31) with the test set. Accuracy of location of the fold along the electrode array was also tested and found to have a RMSE of 0.81 electrodes. In separate clinical studies with properly placed perimodiolar (n=145) and straight (n=20) electrode arrays, the algorithm had a specificity of 98.8% (163/165), higher than found in temporal bones in this study. The candidate algorithm was found to be accurate and has potential to give surgeons actionable feedback on one aspect of the correct placement of cochlear implant electrode arrays without additional exposure to radiation. Future work should validate the use of algorithmic feedback in surgery and extend the functionality beyond checking for folds in the array.

1530: SURGICAL INTERVENTION TRIGGERED BY REAL-TIME INTRA-COCHLEAR ELECTROCOCHLEOGRAPHY DURING IMPLANTATION SAVES RESIDUAL HEARING: OUTCOMES OF A RANDOMISED CONTROLLED TRIAL

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Introduction: Preservation of natural hearing during cochlear implantation is associated with improved speech outcomes, however more than half of implant recipients lose this hearing. Sudden drops in the amplitude of the cochlear microphonic (CM), measured during implantation directly from the cochlear implant’s electrodes, have been shown to predict more severe hearing losses. Here, we report on a trial investigating whether immediate surgical intervention triggered by these drops can save residual hearing.

Methods: A single-blinded and placebo-controlled trial tested whether surgical intervention trigged by CM drops measured during cochlear implantation improved rates of hearing preservation. 60 adults were recruited, all implanted with Cochlear Ltd’s Thin Straight Electrode. The surgical intervention was to withdraw the electrode to recover CM amplitude. The primary outcome was hearing preservation 3 months following implantation.

Results: Sixty patients were recruited; pre-operative audiometry was not significantly different between groups. Post-operatively, hearing preservation was significantly better in the interventional group. This was the case in absolute difference (10dB better), as well as for relative difference (32% better).

Conclusions: This is the first demonstration that surgical intervention in response to intraoperative hearing monitoring can save residual hearing during cochlear implantation.

Attention, Cognition, and Effort – Featured Talks and Posters

Featured Recorded Talk:

1439: TOWARDS DECODING SELECTIVE ATTENTION IN UNILATERALLY DEAFENED SUBJECTS USING COCHLEAR IMPLANT ELECTRODES AS SENSORS

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Decoding attention to a speech stream in a cocktail party-like scenario is a promising line of research in cochlear implant (CI) research. It has been shown that the envelope of an attended speech stream can be reconstructed from single-trial electroencephalography (EEG). Future applications of this technique can be found in closed-loop CIs to fit the device objectively or to brain-steer algorithms for speech enhancement. State-of-the-art high-density EEG is not suitable for such applications in clinical routine or daily life. Instead, the current trend is to develop small and portable EEG devices that are easy to use in a clinical environment and that are less visible for daily-life use. Another alternative is to use the backward telemetry of the CI to record electrophysiological signals from CI electrodes as sensors without the need of extra EEG hardware. The aim of this study was to investigate if it is possible to record cortical signals using the CI electrodes and a novel research backward telemetry system that allows for a single-channel continuous recording.

Five unilaterally deafened subjects implanted with an Advanced Bionics CI participated in the study. In a first step, we recorded cortical auditory evoked potentials (CAEPs). In a second step, we recorded the cortical response to continuous speech stimuli in a selective attention paradigm in which the subject had to attend to one speech stream and ignore a second one. All stimuli were presented acoustically via inserted earphones to the normal hearing ear. The EEG was recorded with a high-density scalp EEG and additionally with the CI electrodes in the contralateral ear. The EEG recordings were used to reconstruct the envelope of the attended speech stream using a linear model.

CAEP morphologies were successfully detected in all subjects with high-density scalp EEG and in some subjects with CI-based recordings. The results show that it was possible to reconstruct the envelope of the attended speech streams, whereby the decoding accuracy was highest with high-density scalp EEG. We found decoding accuracies above chance level in all five subjects using the high-density EEG, in four of five subjects using a single-channel scalp EEG and in three of five subjects using the CI-based recordings. The quality of CI-based recordings varied widely between patients, probably due to different CI electrode locations and orientations with respect to the auditory cortex.

In conclusion, this study shows that it is feasible to reconstruct the envelope of an attended speech stream from single-channel scalp EEG and also from single-channel CI-based recordings. These findings pave the way towards making EEG more applicable in the clinic, for example, for an objective closed-loop CI fitting and for future brain-steered CIs. However, the study also points out towards further improvements of the CI backward telemetry systems.

Acknowledgements: We would like to thank Kanthaiah Koka and colleagues from Advanced Bionics for providing research tools and advice, as well as Joseph Attias and Suhail HabibAllah from the University of Haifa for sharing their experience on CAEP measurements with BEDCS. This work was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Excellence Strategy - EXC 2177/1 - Project ID 390895286.

Featured Recorded Talk:

1321: EXAMINING EXECUTIVE FUNCTION AND ITS RELATIONSHIP WITH LANGUAGE OUTCOMES IN PAEDIATRIC COCHLEAR IMPLANT RECIPIENTS: A BEHAVIOURAL AND FUNCTIONAL NEAR-INFRARED SPECTROSCOPY (FNIRS) STUDY

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Introduction. Executive Function (EF) is a set of cognitive processes that consists of three core components: working memory, inhibition control and cognitive flexibility [1]. The literature often reports a reciprocal and bidirectional relationship between EF and language performance in children with cochlear implants (CIs). However, the vast majority of studies investigating this relationship have been cross-sectional in design, hence it has been difficult to establish whether EF can predict future language outcomes and/or vice versa. Behavioural measures of EF are often difficult to obtain in infants and preschool children. Objective cortical measures of EF may avoid the problem of solely relying on behavioural measures and therefore assist clinicians in predicting which children are at risk of EF delays.

Methods. We used functional near-infrared spectroscopy (fNIRS), a non-invasive imaging technique, to measure cortical activation whilst both normal-hearing (NH) children and profoundly-deaf children with CIs performed behavioural EF tasks. Specifically, within a longitudinal study design, infants were followed from pre- to post-cochlear implantation. We also acquired parent-reported measures of both EF and language ability using the Behaviour Rating Inventory of Executive Function (BRIEF) and the Children's Communication Checklist (CCC-2) respectively. Our aim was to identify cortical activation in response to behavioural EF tasks that may prove useful to predict future language outcomes.

Results. Analysis of parent-reported measures revealed that children with CIs scored lower on language measures and had poorer EF than their NH peers (4 – 6 years old; NH $n = 41$, CI, $n = 42$). Increasing BRIEF scores (worsening EF) were negatively correlated with CCC-2 performance in both groups (NH; $r = -0.5$, $p <0.01$, CI; $r = -0.6$, $p <0.01$). A cross-sectional fNIRS imaging study confirmed that both NH children and children with CIs had increased cortical activation overlying prefrontal, left inferior frontal and left auditory areas during behavioural EF tasks (4 - 6 years old; NH $n = 18$, CI $n = 2$). Interestingly, this observed cortical activation was greater in NH controls, compared with CI participants. Ongoing analyses of longitudinal infant data aims to determine whether or not early behavioural and cortical measures of EF are able to predict later EF and language performance.

Conclusion. These findings not only demonstrate that behavioural measures of EF and language are significantly correlated in children with CIs, but also that performance in these two domains lags behind that of their NH peers. Furthermore, our results also suggest that it is possible using fNIRS to repeatedly measure behavioural EF-evoked cortical activation in frontal and temporal brain regions. By developing our understanding of how brain regions implicated in EF processing develop in auditory-deprived infants before and after cochlear implantation, it may be possible to help clinicians predict subsequent language development and direct rehabilitation resources to CI recipients who need them most.

Reference. [1] Miyake, A. et al. (2000). The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. Cognitive Psychology, 47 (1), 49-100.

Featured Recorded Talk:

1463: EXAMINING THE USE OF AN AUDITORY BALANCE PROSTHESIS DURING A DUAL BALANCE-COGNITION TASK IN CHILDREN AND YOUNG ADULTS WITH COCHLEOVESTIBULAR LOSS

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Objectives: To: 1) examine how engaging in a balance stance affects cognitive load in children and young adults with cochleovestibular loss and 2) determine if the use of an auditory balance prosthesis impacts performance on these tasks.

Background: Vestibular loss and balance problems are common in children with profound deafness. Maintaining balance requires cognitive resources, and therefore during a dual balance-cognition task, cost can be incurred to one or both tasks. The BalanCI is an investigative prosthesis that integrates with children's cochlear implants to provide auditory head-referencing cues, helping them adjust their posture and remain upright. The present study tested the hypothesis that 1) children and young adults with cochleovestibular loss demonstrate greater dual-task costs when performing a working memory task while engaging in a simple balance stance than typically-developing peers, and 2) using the BalanCI will help alleviate some of these cognitive loads, improving performance on these tasks.

Methods: Fifteen typically-developing children (6 female) aged 7-18 years (mean age ± SD = 13.6 ± 2.75 years) and 8 children and young adults with cochleovestibular loss (6 female) aged 9-27 years (mean age ± SD = 19.5 ± 5.5 years) completed two working memory tasks (auditory backwards digit span task and visuospatial backwards dot matrix task). Each working memory task was completed while seated, while standing in tandem stance with the BalanCI off, and while standing in tandem stance with the BalanCI on. Tandem stance positions were performed on a firm, stationary surface, and kinematic measures were captured using motion capture markers worn on the head, upper body, pelvis and feet. Typically-developing children were presented with cues from the BalanCI bilaterally through insert earphones.

Results: Preliminary analyses suggest poorer working memory in participants with cochleovestibular loss compared to typically-developing children (digit span impairment (95% CI range, $p = 0.02$); dot matrix impairment (95% CI, $p = 0.06$)). There was no main effect of balance condition (seated vs. tandem stance) or BalanCI use on the working memory measures in either group (95% CI, p's > 0.1). Motion capture data is undergoing analysis.

Conclusions: Findings suggest that children with cochleovestibular loss perform more poorly on auditory and visuospatial working memory tasks than typically-developing peers. Additionally, the BalanCI did not impact performance in either working memory task. Future analyses of motion capture data will examine the impact of working memory task and BalanCI use on balance.

1336: CHILDREN-ROBOT INTERACTION AS A STRATEGY TO INCREASE ATTENTION SPAN OF COCHLEAR IMPLANTED CHILDREN DURING AUDITORY TESTS

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Human-robot interaction (HRI) is a multidisciplinary research field, where one of the main studied parameters corresponds to the level of engagement of participants when completing different tasks. Promoting children interacting with a robot has been used as an innovative method for teaching and communicating with them, analysing their social behaviour and task performance when working with the robot.

The present study regards the use of a humanoid NAO robot as an interactive interface for auditory tests used for evaluating the outcome of cochlear-implants (CIs) in children. These tests correspond to the clinically most commonly used tests of speech audiometry in Netherlands. Nederlandse Vereniging voor Audiologie (NVA) phoneme lists are used as an assessment of speech perception, quantified by the number of correctly identified phonemes embedded in meaningful words. The digits in noise (DIN) test is used as an assessment of speech perception in noise, quantified by the number of correctly identified digits presented in background noise. Children's attention span can be very limited during these assessments. They can struggle understanding the instructions and keeping focused throughout the whole test. Even though these tasks usually do not take longer than a couple of minutes, children's mood can easily change, resulting in less reliable outcome measures, which can make it more complex for the clinicians to evaluate the children's performance with their implants.

The purpose of this research is to help facilitate the attention span of the CI children, studying if the HRI can result in a better task performance and easier clinical evaluation of their implant's operation. The implemented child-robot interaction (CRI) protocol consists of three stages: an introduction to the robot, a tactile activity triggering warble tones for audiometric threshold testing and the speech auditory tests (either NVA or DIN). All three stages take part during the clinical follow-up sessions of the CI children at the outpatient clinic in the Department of Otorhinolaryngology, in the University Medical Center Groningen (UMCG). The interaction is video recorded from two angles, one focusing on the child's facial expression and the other one showing the side view of both the child and the robot. The attention span is separately measured for each of the protocol stages from the facial expression and general body language of the child, as well as from their gaze tracking; assuming a positive attitude towards the robot when the child's posture is kept overall constant, thus inferring a higher engagement during the interaction. The results from both audiological and CRI assessments will provide us an overview about further potential robotic applications in the clinic, for other hard of hearing children and adults.

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1368: CORTICAL MECHANISMS OF ACROSS-EAR INTEGRATION STUDIED WITH FUNCTIONAL NEAR-INFRARED SPECTROSCOPY

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Cochlear implants (CIs) can rehabilitate bilateral hearing in listeners with single-sided deafness, who have acoustic hearing in one ear and are deaf in the other (SSD-CI), and in listeners with bilateral deafness who are eligible for bilateral CIs (BiCI). Behavioral studies suggest that patients in both groups benefit from bilateral hearing. Notably, BiCI users can attend to a target talker if the target and an interferer are presented to opposite ears; however, they perform worse than normal-hearing (NH) listeners in more realistic listening configurations[1]. This study examined how NH listeners presented with SSD-CI and BiCI simulations integrate speech that is streamed to both ears in an alternating manner, to assess auditory attention and across-ear integration. We further explored whether neural underpinnings of these effects are revealed in cortical activity patterns measured using functional near-infrared spectroscopy (fNIRS).

To examine across-ear integration, we tested 20 NH listeners, and used sequential segments of spoken sentences alternating between ears at rates of 2, 4, 8, and 32 Hz; a similar paradigm was explored by Wingfield[2] and others. We simulated SSD-CI and BiCI hearing in this group by presenting vocoded speech in the right ear or in both ears, respectively. We expected to observe a V-shaped speech intelligibility function across rates: At low rates listeners might perform well by switching attention between ears, whereas at high rates listeners might perform well by bridging the shorter silent gaps in either ear. At intermediate alternating rates (around 4 Hz), if neither strategy is effective, speech intelligibility should decrease. We obtained speech intelligibility scores using this paradigm, and fNIRS measures in two brain regions: the bilateral auditory cortices (AC), which are sensitive to intelligible speech, and the bilateral dorsolateral prefrontal cortices (DLPFC), which play a role in auditory attention.

Speech intelligibility results in NH and SSD-CI simulated conditions showed that scores were high across all alternating rates. A V-shaped intelligibility function was not observed in either condition, and NH scores were marginally higher than SSD-CI scores at 2 and 4 Hz. In the BiCI simulated conditions, the predicted V-shaped speech intelligibility function with was observed with lowest scores at 4 Hz. BiCI scores were significantly lower than both SSD-CI and NH scores at all alternating rates ($p < 0.001$). For fNIRS data, we will analyze the relationship of fNIRS response amplitudes across rates, listening conditions and brain regions of interest. Initial observations suggest that the left AC (LAC) and right DLPFC (RDLPFC) exhibit differing patterns of activation in response to alternating speech stimuli. Importantly, in conditions with high speech intelligibility scores, cortical activity suggested different listening strategies across the four alternating rates. Addition of degraded speech in SSD-CI and BiCI conditions altered patterns of LAC and RDLPFC activity compared to the NH speech condition. Hence, our preliminary observations suggest that degraded speech inputs in one or two ears impacts across-ear integration of speech stimuli, and that fNIRS measures might reveal differences across conditions not revealed by speech intelligibility data.

Funding: Research funded by the American Otological Society Fellowship Grant to GS, and NIH R01DC003083 to RL.

References: [1] Goupell MJ, Kan A, Litovsky RY. (2016). Spatial attention in bilateral cochlear-implant users. J Acoust Soc Am, 140(3), 1652-1662. [2] Wingfield, A. (1977). The perception of alternated speech. Brain Lang, 4(2), 219-230.

1381: DIVIDED LISTENING IN THE FREE FIELD BECOMES ASYMMETRIC WHEN ACOUSTIC CUES ARE LIMITED

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Objective: Verbal communication in social environments often requires dividing attention between two or more simultaneous talkers. The ability to do this, however, may be diminished when the listener has limited access to acoustic cues or those cues are degraded, as is the case for users of cochlear implants or hearing aids. The aim of the present study was to investigate the ability of normal-hearing (NH) listeners to divide their attention and recognize speech from two simultaneous talkers in simulated free-field listening conditions, with and without reduced acoustic cues.

Design: Participants were asked to recognize and repeat as many words as possible from two simultaneous, time-centered sentences uttered by a male and a female talker. In Experiment 1, the female and male talkers were located at ─15° and +15°, ─45° and +45°, or ─90° and +90° azimuth, respectively. Speech was natural or processed through a noise vocoder and was presented at a comfortable loudness level (~65 dB SPL). In Experiment 2, the female and male talkers were located at ─45° and +45° azimuth, respectively. Speech was natural but was presented at a lower level (35 dB SPL) to reduce audibility. In Experiment 3, the location of the talkers was switched relative to Experiment 2 (i.e., male and female talkers were at ─45° and +45°, respectively) to reveal possible interactions of talker sex and location. Speech was vocoded and presented at a comfortable loudness level.

Results: Listeners recognized overall more natural words at a comfortable loudness level (76%) than vocoded words at a similar level (39%) or natural words at a lower level (43%). This indicates that recognition was more difficult for the two latter stimuli. On the other hand, listeners recognized roughly the same proportion of words (76%) from the two talkers when speech was natural and comfortable in loudness, but a greater proportion of words from the male than from the female talker when speech was vocoded (50% vs 27%, respectively) or was natural but lower in level (55% vs 32%, respectively). This asymmetry occurred and was similar for the three spatial configurations. These results suggest that divided listening becomes asymmetric when speech cues are reduced. They also suggest that listeners preferentially recognized the male talker, located on the right side of the head. Switching the talker's location produced similar recognition for the two talkers for vocoded speech, suggesting an interaction between talkers' location and their speech characteristics.

Conclusions: For natural speech at comfortable loudness level, listeners can divide their attention almost equally between two simultaneous talkers. When speech cues are limited (as is the case for vocoded speech or for speech at low sensation level), by contrast, the ability to divide attention between talkers is diminished and listeners favor one of the talkers based on their location, sex, and/or speech characteristics. Findings are discussed in the context of limited cognitive capacity affecting dividing listening in difficult listening situations.

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1397: THE IMPORTANCE TO INVESTIGATE INDIVIDUAL COGNITIVE ABILITIES WHEN ASSESSING THE OUTCOMES OF NEW COCHLEAR IMPLANT PROCESSING STRATEGIES AND FEATURES: EXAMPLES FROM TWO RESEARCH PROTOCOLS

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The great individual differences in the outcome measures for CI users, especially in adverse conditions, pose great difficulty for researchers and clinicians to maximise the benefit of CI devices for real users. Past studies have shown how sensory factors could explain some of the individual differences. The contributions of central cognitive factors to speech recognition for adult CI users have only recently been explored.

Typically, CI users need to allocate a greater share of central processing resources to cope with the degraded inputs at the auditory periphery. How well CI users extract effective speech information from the inputs could depend on individual cognitive capacity and efficiency: to store and process the activated phonological and lexical competitors from the ambiguous inputs, reject incorrect candidates, and fuse ambiguous information into a complete percept. Indeed, past studies have shown that hearing loss patients gain different amount of benefit from processing strategies due to their individual differences in cognitive skills. It is likely that an improved CI processing solution might not provide same improvement in speech recognition and listening effort for every CI user. Research projects will gain more insights when looking beyond the average improvement across CI users and investigate how the cognitive abilities could predict the effectiveness of new CI strategies and features.

Therefore, this abstract will propose a test paradigm that is currently used in two research protocols to highlight the importance and benefits to consider individual cognitive differences when assessing the benefits of next generation CI processing strategies.

A comprehensive set of outcome measures are collected when comparing CI users' performance using the noise reduction feature (VoiceTrack) and next generation CI processing strategy. The outcome measures include consonant speech recognition, listening effort in noised conditions, subjective sound quality rating and melody recognition. A group level comparison is then performed to quantify the benefit of the feature and strategy. Then, to investigate the benefit on an individual level, a few cognitive tests are selected (forward- and backward- digit span; N-back; visual Stroop task; Progressive matrix) to test on CI participants. The tests will be implemented using the Oticon Medical Experiment builder (OMEXP), a software for designing and running cognitive hearing experiments, which includes advanced audio capabilities and integrates lab streaming layer to record synchronously various data (i,e., pupillometry). The results will be correlated with differences in other outcomes measures to identify the group of CI users who would benefit the most from the strategy and explain the variability in the benefits.

Collecting the cognitive profiles of CI users will help us to understand the real benefit of next generation processing strategy on CI users and tap into CI users' listening strategies. Eventually, it will pave the way for better individualisation in CI fitting and new strategy development.

1443: ASSESSING INHIBITORY CONTROL AND LISTENING EFFORT, USING EEG AND PUPILLOMETRY, IN RESPONSE TO ADVERSE LISTENING CONDITIONS AND MEMORY LOAD

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Profoundly deaf adults are currently treated with a cochlear implant (CI) yielding substantial hearing benefits. Unfortunately, speech perception outcomes are not consistent across CI users (e.g. Holden et al., 2013). The majority of studies so far focus on bottom-up auditory input and several biological and audiological factors to explain and reduce a part of this variability. However, speech-perception studies in normal-hearing adults show that top-down neurocognitive factors can compensate for the loss of acoustic information as well. Here, we studied how effortful listening becomes, when these compensatory mechanisms need to be activated while listening to a distorted speech signal through a CI vocoder.

Previous studies by Obleser and colleagues (J. NeuroSci. 2012 vol:32) and Petersen and colleagues (F. Psych. 2015, vol:6) in participants with normal hearing and with various degrees of hearing loss, respectively, implemented a suitable protocol to investigate inhibitory control, a mechanism involved in ignoring task-irrelevant information, facilitating identification of correct items and inhibiting incorrect responses and working memory load. EEG was measured to assess neuronal alpha-band activity, associated with inhibitory control, during an auditory digit working memory task, in which memory load and acoustic degradation were manipulated. They found that neuronal alpha activity in the parietal lobe increases with increasing memory load and acoustic degradation.

We extended their paradigm by also measuring pupil dilation. We expect that listening effort (and pupil dilation as its proxy) has a non-monotic relationship to both memory load and acoustic degradation. Furthermore, we expect individual differences in coping strategies being reflected in pupil dilation and oscillation measures.

The results of the current study will help guide further research exploring variability in speech perception performance in adult CI users due to top-down neurocognitive factors. We will apply a similar paradigm to adults with postlingually acquired severe-to-profound bilateral hearing loss using a CI. Identifying neurocognitive factors that explain variability in adult CI users can help clinicians in predicting postoperative outcomes and in guiding counselling and training of CI users, to gain better results in hearing rehabilitation.

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1458: USING 3D AUDIO TO ASSESS SPATIAL SPEECH IN NOISE PERFORMANCE

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Aim. Everyday communication surroundings are typically complex. Signals of interest are often degraded by background noise and may change their location, or there may be multiple sources that the speaker needs to follow. However, most clinical tests of speech recognition do not use environments which are representative of the daily challenges faced by the listeners. Assessing spatial listening skills usually requires the use of a loudspeaker array, which is costly in terms of space and resources. Our aim is to overcome this problem by implementing the Spatial Speech in Noise test (Bizley et al, 2015) on a virtual acoustics platform to deliver complex listening environments via headphones.

Methods. A Virtual Acoustics (VA) version of the Spatial Speech in Noise (SSiN) test, the SSiN-VA, was implemented using the 3D Tune-In Toolkit (Cuevas-Rodríguez et al, 2019) to simulate seven loudspeaker locations from –90º to 90º azimuth, at regular 30º intervals. This test simultaneously assesses speech recognition and relative localisation at dynamically changing source locations, with a babble background. Using this dual-task paradigm increases the cognitive load for the listener. In Experiment 1, the typical responses of normal-hearing participants were determined and compared to those of the original SSiN test which was implemented in a loudspeaker array in an anechoic chamber. Dual-task results will be compared to the outcomes for the individual tasks alone to understand the impact of increasing the cognitive load. In Experiment 2, the same measures will be conducted with bilateral cochlear-implant users.

Results. Preliminary outcomes from seven normal-hearing listeners suggest that the patterns of responses with the SSiN-VA are similar to those reported by Bizley et al. (2015) for a loudspeaker implementation. While relative localisation performance tended to be best at around the midline and worse at the lateral locations, the reverse pattern was found for speech discrimination.

Conclusion. We have implemented the SSiN-VA test and preliminary findings with normal-hearing listeners indicate that the virtual acoustics implementation results in equivalent response patterns as obtained using the speaker array. Further testing to better understand the sensitivity of the test and the impact of the dual-task paradigm will be conducted.

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1466: VISIBLE AND INVISIBLE LISTENING EFFORT IN PEOPLE WHO USE COCHLEAR IMPLANTS

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Listening effort is widely recognized as an important problem in understanding speech perception with a cochlear implant, but there are still major problems that remain overlooked. This study targets two specific ways that listening effort can be accidentally neglected, but which are important for communication. The first is the situation where a CI listener appears to perceive a sentence correctly, but needed to mentally correct a missing or misperceived word in the sentence. We assessed the effort of mental correction using sentences where specific words were missing or mispronounced, but recoverable from later context. Increased effort was inferred from changes in pupil dilation that were time locked with the misperceived word and the subsequent context.

The second situation in which we demonstrate that effort can be overlooked was an examination of how well effort can be detected in the voice of a cochlear implant user. CI listeners' verbal responses from the mentally-corrected-word study were recorded and played for new listeners whose job was to detect which responses resulted from sentences that required effortful mental correction versus regular sentences. Very low d-prime scores suggest that those judges have virtually no ability to discriminate more- or less-effortful responses, even when they had personal experience communicating with friends or family members who have hearing loss, and even when they were professional audiologists.

The results of these two studies suggest that effortful listening can be overlooked by tests that do not distinguish perceptions that were correctly mentally reconstructed versus genuinely-correct perceptions, and that vocal signatures of effort are not reliably audible by an external listener. Both of these problems – overlooking effort, and failure to signal effort – can hide the difficulty of listening, compounding its effects. These results are highlighted to inspire discussion of how to make effort more visible, while balancing the privacy and comfort of those who experience effort.

1516: NEURAL CORRELATES OF VISUAL STIMULUS ENCODING AND VERBAL WORKING MEMORY THAT ARE RELATED TO SPEECH-IN-NOISE PERCEPTION IN COCHLEAR IMPLANT USERS

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A common concern for individuals with severe-to-profound hearing loss fitted with cochlear implants (CIs) is difficulty following conversations in noisy environments. Recent work has suggested that these difficulties are related to individual differences in brain function, including verbal working memory and the degree of cross-modal reorganization of auditory areas for visual processing. However, the neural basis for these relationships are not fully understood. Here, we investigated neural correlates of visual verbal working memory and sensory plasticity in 14 CI users and age-matched normal-hearing (NH) controls. While recording high-density electroencephalography (EEG), participants completed a modified Sternberg visual working memory task where sets of letters and numbers were presented visually and then recalled at a later time. Results suggested that CI users had comparable behavioral working memory performance compared to NH. However, CI users had more pronounced neural activity during visual stimulus encoding, including stronger visual-evoked activity in auditory and visual cortices, larger modulations of neural oscillations, and increased frontotemporal connectivity. During memory retention of the characters, CI users, in contrast had descriptively weaker neural oscillations and significantly lower frontal-temporal connectivity. These results reveal differences in neural correlates of visual encoding and working memory in individuals with CIs.

1538: ELECTROPHYSIOLOGICAL CORRELATES OF SUBJECTIVE COGNITIVE DEMAND IN COCHLEAR IMPLANT USERS DURING LISTENING IN NOISE

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Although cochlear implantation is a generally successful avenue of hearing restoration, there is still considerable variability and differences for speech recognition outcomes for cochlear implant (CI) listeners which cannot be explained. A potential factor that may affect outcome variability is the poor degree that clinical testing environments and stimuli reflects listening in real-world environments, which demands a greater amount of cognitive resources serving working memory and attention compared to listening in a quiet and controlled sound booth. The current study examined the how well the brain “follows” natural audiovisual conversations in the presence of multi-talker background noise. Video and audio segments from a dialogue-based television show were presented to 15 adult CI listeners in high, moderate, and low levels of background noise while electroencephalography (EEG) was concurrently recorded. Brain speech tracking to the speech envelope was measured using a linear ridge regression method, and self-reported ratings of cognitive demand for each listening condition were collected using the NASA Task Load Index. Preliminary findings reveal that self-reported mental demand decreases as background noise levels decrease, with concomitant decreases in brain tracking. Comparison between audiovisual and audio only conditions suggests that the addition of visual cues assists in speech recognition. These results suggest that meaningful information about the cochlear implant listening experience can be extracted from brain responses using “ecological” stimuli such as a normal conversation.

Auditory Plasticity and Training – Invited and Featured Talks + Posters

Invited Recorded Talk:

1523: AUDITORY SKILL LEARNING

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Much effort has been devoted in the past years to improving auditory perception for hearing impaired individuals who use cochlear implants (CI). Technological means that are aimed to enhance the resolution of the signal at the periphery level resulted in a significant but limited benefit, supporting the notion that top-down cognitive mechanisms need to be actively involved to compensate for the degraded input provided by the CI. One way to invoke efficient high-level cognitive and auditory processing of the incoming signal is via auditory training that can direct the auditory system to attend to the relevant acoustic properties of the stimuli. However, the characteristics of the learning process that may follow such training and the magnitude of the training-induced improvements in auditory perception are still largely unknown, even for listeners with normal hearing (NH). In the current lecture I will review recent studies from our lab that aimed to characterize auditory skill learning in NH listeners and to explore its dependency on training-related factors, including the length of training, the testing and the training method, and subject-related factors, including cognitive abilities and age. Specifically, I will describe how and when these factors may affect the time course of learning, the consolidation, retention and generalization of the learning gains, using a basic psychoacoustic task of frequency discrimination for training. I will also present a model that predicts the efficiency of auditory skill learning in school-age children, depending on the maturity of their bottom-up auditory processing and top-down cognitive abilities. Following the lecture, listeners will better understand the potential and constrains of auditory learning and will gain an important insight on brain plasticity at childhood and adulthood. The findings will show that the characteristics of auditory learning resemble those shown in the visual and motor modalities, and will support the notion of common underlying mechanisms for basic skill learning across different modalities. They will further suggest that the effect of the training protocol and the conditions of training may largely depend on the learner's top down and bottom-up processing capabilities. This information may help to set realistic expectations regarding the outcomes of auditory training in pathological populations, including CI users, and will support the view that training may best be tailored for each patient individually, depending on his or her cognitive and auditory abilities.

Featured Recorded Talk:

1390: STIMULUS-SPECIFIC DIFFERENCES IN CROSS-MODAL ACTIVITY AND FUNCTIONAL CONNECTIVITY IN POST-LINGUALLY DEAF CI USERS USING FUNCTIONAL NEAR INFRARED SPECTROSCOPY (FNIRS)

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Introduction: Sensory deprivation can lead to 'cross-modal' cortical changes, whereby deprived brain regions may be recruited by other intact sensory systems. Cross-modal auditory cortical responses to visual stimuli have been reported in post-lingually deafened cochlear implant (CI) users, with suggestion that this could be detrimental to speech understanding, however there is no clear consensus. Typically, cross-modal activity has been quantified by measuring amplitude of activation within an anatomically-defined region in response to a visual or auditory stimuli, e.g. activation to visual stimuli in a classically 'auditory' area or activation to auditory stimuli in a 'visual' area. Further, heterogeneity in stimuli has been used to assess this, e.g. 'non-speech' vs. 'speech-based' stimuli, which could arguably engage different functional networks. We proposed that cross-modal activations more broadly represent activity of multimodal cortical networks in the brain, specifically interregional connections, and the distributed nature of current theoretical models of cortical language processing in humans. We therefore hypothesized that differences in cross-modal activation patterns and reported associations with functional speech outcomes in post-lingually deaf CI users are related to the type of stimuli used to measure cortical activity, and may reflect engagement of different functional brain networks.

Methods: Functional near-infrared spectroscopy (fNIRS) was employed to assess activation of auditory and visual cortices to non-speech and speech stimuli in CI users (final n=14) and age-matched, normal-hearing (NH) subjects (n=17). Two test paradigms were administered in a block design, using 1) non-speech auditory and visual stimuli - modulated speech-shaped noise and morphing concentric gratings, and 2) speech stimuli - concatenated IEEE sentences presented in an auditory-only and a visual-only condition. Responses were measured via optode arrays positioned bilaterally over superior temporal 'auditory' regions and occipital, 'visual' regions of interest (ROIs). Behavioural speech understanding was assessed in both auditory and visual conditions. Coherence, a measure of both response amplitude and phase, was used to examine task-related connectivity between auditory and visual regions of interest. Linear mixed effects modelling was used to examine fixed effects of group, condition and stimulus type and their combined interaction, with 'subject' specified as a random effect. Spearman's rank-order correlation was used to examine the relationship between task-related brain activity and behavioural speech measures.

Results: Evidence of cross-modal activity was observed in both NH and CI participants. The left superior temporal gyrus showed greater activation to visual speech when contrasted with the non-speech stimuli in both NH [$t(116)=2.61$, corrected $p=0.029$,] and CI [$t(116)=3.83$, corrected $p=0.004$] subjects. Performance on a visual speech (lip-reading) task was positively associated with brain activation in the left auditory ROI in CI participants [$r_s=0.73$, corrected $p=0.003$], however nil significant associations were observed between cortical activity and auditory-only speech understanding. Task-related connectivity (coherence) between left auditory and visual ROIs in response to visual stimuli showed a significant fixed effect of group $F(1,761)=22.55$, corrected $p<0.001$], and an interaction between group and stimulus type (speech vs. non-speech) [$F(1,746)=4.90$, $p=0.03$], but not for right auditory–visual or left auditory–right auditory ROI pairs. Significantly greater coherence between left auditory and visual ROIs to visual speech stimuli [$t(758)=5.13$, corrected $p<0.001$] was observed in CI users compared to NH subjects. Further, CI users showing increased coherence between left auditory and visual ROIs in response to visual speech, demonstrated better auditory speech-in-noise understanding [$r_s=-0.70$, $p= 0.008$]. The same relationship for understanding auditory speech-in-noise was not statistically significant [$r_s=-0.14$, $p=0.665$] for coherence values between the same two regions for visual non-speech stimuli.

Conclusions: Together, our data suggest that cross-modal activity to visual stimuli in typically 'auditory' areas in post-lingually deafened CI users is stimulus-specific, and that rather than necessarily being the consequence of mal-adaptation to sensory deprivation and subsequent restoration, may also reflect activity of multimodal cortical networks that contribute to speech processing, particularly where language-based stimuli are used. Functional connectivity measures may therefore be even more informative than purely amplitude-based measures (e.g. amplitude of BOLD response alone in a discrete brain region) in understanding cross-modal activity and cortical processing in general. Accessing these functional networks, including through specific language training tasks, could be a key to improving listening performance by CI users, and other hearing-impaired individuals.

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1315: COMPUTER-ASSISTED TRAINING FOR FRENCH COCHLEAR IMPLANT USERS

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In France, clinical auditory rehabilitation is typically provided during the first year of cochlear implant (CI) use. While this in-person rehabilitation benefits many CI patients, it is not convenient and requires substantial time resources on the part of the clinician and patient; This can be problematic, especially when appointments are not available, as with the COVID-19 crisis. Also, training methods sometimes differ across clinical sites, which can make for an inconsistent training approach. Computer-based auditory training has been shown to improve speech understanding in English- and Mandarin-speaking CI users. We recently developed a similar French language computer-based auditory training program, consisting of more than 1000 words, phonemes, and sentences produced by multiple native French talkers. The training approach was similar to previously developed software (e.g., adaptive training based on phonemic contrasts, with the degree of difficulty tailored to individual CI patients).

We recently conducted a pilot study to evaluate the training software in 15 CI patients (5 unilateral, 5 bilateral, 5 bimodal) who trained at home. All patients had more than 1 year of experience with their CIs. Before training was begun, baseline vowel, consonant and speech reception thresholds (SRTs) for sentence recognition in noise were tested. These tests were first evaluated on normal-hearing (NH) listeners to ensure that the stimuli and test methods were valid; performance in quiet was near-perfect and performance in noise was within the range reported in other studies. Unilateral CI patients were tested with a single CI. Bilateral CI patients were tested with each CI ear alone and with both ears. Bimodal CI patients were tested while listening with the CI alone and with both ears. For all patients, vowel recognition with the CI alone was repeatedly tested until achieving asymptotic performance before beginning the home training. Participants then loaded the software onto their home computers and were instructed how to perform the training. Participants were asked to train for a half-hour per day, 5 days a week, for 1 month (10 hours total training). Unilateral and bimodal patients trained with the CI alone; bilateral patients trained with the poorer ear alone. Baseline testing was repeated immediately after training was stopped and then one month after training was stopped to observe whether any training benefits were retained.

Across all subjects, results showed that vowel, consonant, and SRTs significantly improved in the trained CI ear ($p<0.05$ in all cases). Follow-up measures showed that performance remained significantly better than before training ($p<0.05$ in all cases). For bilateral and bimodal CI users, speech performance also significantly improved when listening with both ears ($p<0.05$ in all cases), suggesting that training one CI ear improved bilateral or bimodal performance with both ears.

These preliminary data suggest that the French language computer-assisted training software may significantly benefit French CI users, and that training one CI ear with phonemic contrasts may generalize to improved sentence recognition in noise, as well as to improved bilateral/bimodal performance. Such computer-based training at home may complement clinical auditory rehabilitation and may be especially valuable when in-person rehabilitation is not possible.

1440: CORTICAL RESPONSE TO A CHECKERBOARD, REVEALED THROUGH EEG AND FNIRS, IN CHILDREN WEARING COCHLEAR IMPLANTS

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Objective: Over the first few years of life, the brain organizes itself in response to the environment. In the case of deafness, the brain may recruit the auditory cortex to allocate more resources to vision, a potentially maladaptive phenomenon for a deaf child who receives a cochlear implant (CI) later in life. The present study aimed to observe this cross-modal plasticity for low-level visual processing in children implanted before their fourth birthday, and examine whether this is somehow related to their language development.

Design: Seventy-five children (7 to 18 years old) were allocated to three groups. Group CIp and CIg consisted in 24 and 26 children with CIs, having poor or good outcomes in terms of spoken-language abilities, a difference partly accounted for by their age at implantation. Group NH was a control group consisting in 25 children with normal hearing. High-density electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) were used, one after the other, to record the cortical response to a rotating checkerboard.

Results: The EEG data revealed strong occipital potentials which were larger in groups CIg or NH than in group CIp. The fNIRS data revealed strong occipital activation, with a different topography across the three groups: group CIp exhibited the most activation in V1 while groups CIg and NH exhibited a more spread occipital activity. In both EEG and fNIRS data, the frontal and motor responses were inversely related to the occipital response, but neither of these three regions, were predictive of language outcomes. In contrast, the temporal cortices (bilaterally) were deactivated in many NH and CIg children but not in CIp children, particularly for those implanted late, who possessed the poorest language / literacy outcomes.

Conclusion: Brain regions associated with auditory processing were not deactivated (or possibly recruited) in a very simple visual task by implanted children, and this contributed to their poor language development. Yet, this recruitment by vision was not accompanied by a greater occipital response to the checkerboard but rather a narrower response, refining the simplistic idea that the visual system becomes more dominant with deafness.

1454: PREFERENCE FOR NON-STANDARD FREQUENCY MAP IS UNAFFECTED BY EXPERIENCE: A CASE STUDY

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The current standard of care for postlingually deaf CI patients involves the use of a default, fixed frequency map. Each manufacturer has a different default, but that default is used for virtually every patient. The unstated expectation is that postlingually deaf CI users will adapt to the non-physiological frequency-place functions introduced by most CIs. Although this approach seems to work well with many patients, there is mounting evidence that some experience incomplete adaptation. Here, a recently implanted, postlingually deafened patient, self-selected an alternative Frequency Allocation Table (FAT) eight days after initial activation. This was compared to the standard FAT over the following three months, using both subjective ratings and speech perceptions tests (both of which were administered in double-blind fashion).

The 72 year old, bimodal CI user was tested on day eight post-activation. An intelligent and articulate woman, she reported that almost all FATs were unacceptable and “did not even sound like speech.” The unacceptable FATs included the standard FAT (188-7938 Hz) in her own speech processor. The only exception was the 313-7938 Hz FAT, about which she said, “I couldn’t make out anything but at least I knew it was speech.” Her double-blind sound quality ratings were only a “1” for this FAT (on a 0-10 scale, described as “very poor”) and a “0” (described as “unacceptable”) for all other FATs, including the standard FAT which is the only one she had had access to thus far. The 313-7938 Hz FAT also resulted in lower perceived effort (7 vs. 10) and clarity (1 vs. 0). We saw her again at 22 days post-activation, and despite only having access to the standard FAT, she still reported better clarity, sound quality, and lower effort with the 313-7938 Hz FAT. Thus, the alternative FAT was programmed into the subject’s clinical processor next to the standard FAT. She was instructed to try both MAPs for equal time (three- to four-hour segments) during the following month. After one month of side-by-side use she reported overall better satisfaction with the alternative FAT. Blind speech testing revealed 24% vs. 14% CNC words and 50% vs. 38% AzBio in quiet with the alternative and standard FATs respectively. In other words, she made progress with both FATs but the advantage for the alternative FAT, both in terms of speech perception and sound quality, remained at 2 and 3 months post activation. In her latter most interval (3-month evaluation) her CNC scores were 64% vs. 40% and her AzBio in noise scores were 33% vs. 16% with the alternative and standard FATs respectively.

In summary, this patient showed adaptation to the CI in the sense that all subjective ratings and speech scores improved over time, for both FATs. On the other hand, she failed to adapt completely to the standard FAT even after periods when it was the only one she used. Again, all subjective reports (questionnaires) and speech testing were conducted blindly. It is interesting that such a consistent and persistent difference was noted for the alternative and standard FATs given that the corresponding frequency-place functions differ by less than 1 mm of displacement along the cochlea.

1455: NEUROMODULATION ENHANCES PLASTICITY IN A RAT MODEL OF COCHLEAR IMPLANT USE

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Rates of auditory perceptual learning with cochlear implants are highly variable across patients. Adaptation to cochlear implants is believed to require neuroplasticity within the central auditory system. However, mechanisms by which behavioral training enables plasticity and improves outcomes are poorly understood. One potent factor enabling plasticity is the neuromodulator norepinephrine from the brainstem locus coeruleus. Here we examined behavioral responses and neural activity in locus coeruleus and auditory cortex of deafened rats fitted with multi-channel cochlear implants. Animals were trained on a reward-based auditory task, with considerable individual differences of learning rates and maximum performance. Photometry from locus coeruleus predicted when implanted subjects would begin responding to sounds and longer-term perceptual accuracy. Auditory cortical responses to cochlear implant stimulation reflected behavioral performance, with enhanced responses to rewarded stimuli and decreased distinction between unrewarded stimuli.

We also examined the effect of pairing locus coeruleus stimulation with an auditory stimulus on auditory learning when the animal had to relearn a tone identification task after cochlear implantation. Prior to daily behavioral training sessions, rats underwent 5-10 min pairing sessions either with optogenetic locus coeruleus or sham stimulation. Learning was accelerated in animals subjected to locus coeruleus stimulation. We then conducted multi-unit recordings in the auditory cortex to assess responses to the cochlear implant. Animals that underwent pairing had a sharper representation of the target cochlear implant channel, and across all animals cortical responses to target, but not foil channels correlated with behavioral performance. These studies indicate that neuromodulation can play a powerful role in shaping outcomes with cochlear implant use and training.

1480: TONOTOPIC MISMATCH IS ASSOCIATED WITH POORER SPEECH PERCEPTION IN SSD PATIENTS

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When single-sided deaf (SSD) cochlear implant users select an acoustic representation (delivered to their normal ear) that provides the best match to what they hear through the cochlear implant, their selections can provide a speech-based estimate of tonotopic mismatch. Our initial results have been largely consistent with estimates of tonotopic mismatch obtained from electroacoustic pitch matching. Namely, we have confirmed that: (a) postlingually deafened CI users experience tonotopic frequency mismatch; (b) this mismatch tends to decrease with experience; and (c) this adaptation process is not always complete.

Fifty-five “single-sided deaf” or SSD CI users were tested over a total of 101 testing sessions. Each listener self-selected an acoustic model that sounded most similar to the CI. The analysis filters of the model were identical to those in the CI, whereas the low- and high-frequency edges of the output carriers (tones or noise bands) were adjusted by the listener. This provided a window into what the CI sounds like as well as the amount of tonotopic mismatch, which is estimated by the frequency difference between the analysis filters and the listener-selected output carriers. We examined potential associations between tonotopic mismatch, time after initial activation, electrode insertion depth, and speech perception scores. A control group of 15 normal hearing listeners participated in a similar experiment using a fixed-frequency real-time vocoder (instead of a CI) presented to one ear, to determine whether the self-selection process yields accurate estimates of frequency mismatch.

Our previous findings were replicated with a larger data set. Self-selected acoustic models were deemed a reasonable acoustic representation of a CI: speech perception scores were similar to those obtained with the CI alone, and similarity ratings were high (6.17 on a 1-9 scale where a rating of 7 represents “very similar”). Tonotopic mismatch was lower for participants with deeper electrode insertion depths, and it tended to decrease with additional listening experience. The present data also reveals a moderate, highly significant negative correlation between tonotopic mismatch and speech perception outcomes. The normal hearing experiment validated our method to measure tonotopic mismatch for the most apical (low frequency) electrode, but not for the most basal (high frequency) electrode.

In conclusion, we found further support for the hypotheses listed above, which were also strengthened by the NH control experiment. We also found that speech perception outcomes are associated with tonotopic mismatch, suggesting that mismatch reduction may be beneficial not only in terms of sound quality but also speech perception.

1499: CORTICAL TRACKING OF SPEECH ENVELOPE IN CHILDREN WITH COCHLEAR IMPLANTS AND HEARING CHILDREN

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Cochlear implantation for the treatment of congenital deafness has been highly successful, however the outcomes for speech perception remain highly variable (Tobey et al 2012). A long-standing issue in the field has been how best to assess the quality and content of speech percepts that children with cochlear implants experience and how the nature of the signal may change under conditions of multi-modal (auditory and visual) stimulation. We make use of a novel electrophysiological paradigm (Backer et al., 2020) to obtain EEG data during children's perception of continuous speech with interposed visual stimulation. We make use of predictive modelling to quantify the relationship between features of sensory stimulus (e.g. speech envelope) and the EEG signal. In the study the participants (CI N = 7, mean age 6y, mean age of implantation 17m; hearing control N = 7 (mean age 6y 5m)) were instructed to watch a silent cartoon presented in the middle on the screen. Around the cartoon two concentric checkered rings in the background flickering at different frequencies (7.5 and 12 Hz). Auditory stimuli consisted of 49 unique sentences (sampled at 22,050 Hz) from the Harvard/IEEE Corpus (IEEE 1969) that were concatenated into a 2-minute long WAV file of continuous speech. Periods of ambient speech occurred in the presence and absence of the visual flicker stimulation. To quantify our EEG data we are making use of novel computational techniques. The mTRF method of predictive modeling of neural processes involves fitting a temporal response function that describes a mapping between features of sensory stimulus like speech envelope and the EEG signal (Crosse et al., 2016; Di Liberto et al., 2015). The EEG data then were filtered between 1 and 15 Hz and ICA was performed to remove ocular and CI-induced artifacts. Using this method, we hope to compare entrainment to speech envelope in hearing and CI children. To the best of our knowledge this method has not been applied to pediatric populations with cochlear implants. Preliminary data analysis has shown higher correlation scores between reconstructed and original envelope in CI group comparing to hearing group ($r = 0.09$, $p < .0001$ for hearing group and $r = 0.16$, $p < .0001$ for CI group). This might reflect better envelope tracking in CI group as it has been shown that individuals with hearing impairments show enhanced envelope tracking when compared to hearing counterparts (Decruy et al., 2020).

Outcomes and Predictive Factors – Invited and Featured Talks + Posters

Invited Recorded Talk

1524: EFFECT OF TEST REALISM ON SPEECH UNDERSTANDING IN NOISE FOR BILATERAL COCHLEAR IMPLANT USERS

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The real-world experience of cochlear implant (CI) users' ability to understand speech in noisy environments often does not correlate well with the outcomes of laboratory assessments. This may be due to the rather artificial speech and noise stimuli used, which do not well reflect the complex acoustic properties of real-world environments. To understand the effect of test realism on individual sentence recall outcomes, 15 bilateral CI users were tested in three different conditions: (1) standard BKB sentences in babble noise, (2) standard BKB sentences in recorded realistic environments reproduced by a 3D loudspeaker array, and (3) realistic sentences taken from natural conversations and presented in the same realistic environments. Two environments were considered with signal-to-noise ratios of -2.2 and 1.4 dB, respectively. Performance decreased with increasing stimulus realism and varied significantly across participants. Average scores were 78% and 92% in the least realistic environments and decreased to 37% and 70% in the most realistic environments. The effect of the realistic noises was well predicted by the U50 derived from the output of the CIs' directional microphones. This was not the case for the realistic speech material, for which the modulation spectrum and overall clarity may be of additional relevance.

Invited Recorded Talk

1519: ECOLOGICAL MOMENTARY ASSESSMENT: OPPORTUNITIES AND APPLICATIONS IN HEARING DEVICE EVALUATIONS

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Evaluations of hearing devices are commonly undertaken with speech tests and questionnaires under controlled conditions. For speech tests, words or sentences are typically presented in quiet or in (mostly stationary) noise coming from one or two loudspeaker directions. Questionnaires in use focus on the experiences in predefined listening conditions made in a past time period, e.g., the last four weeks, and the results are potentially biased by memory effects. Both methods, speech tests and questionnaires, suffer from limitations regarding their ecological validity and rarely consider the individual’s specific demands in everyday life listening conditions. Hence, evidence of individual benefit is sometimes missing. An alternative approach called ecological momentary assessment (EMA) is rapidly gaining widespread use. It employs repeated assessments of individual everyday situations. Smartphones facilitate the implementation of questionnaires and rating schemes to be administered in the real life of study participants or patients during or shortly after the experience. In addition, objective acoustical parameters extracted from head- or body-worn microphones and/or settings from the device’s signal processing unit can be stored alongside the questionnaire data. The advantages of using EMA include participant-specific context-sensitive information on activities, hearing-related experiences, and preferences. The collected data allow for describing the “auditory reality” of participants and opens up new insights into individual everyday hearing abilities. The method offers opportunities to complement results collected under controlled conditions and to enhance patient-centered health care. Challenges are among others compliance, usability of the EMA equipment, and the analysis of diverse individual data. This presentation will review the methodology and give examples for applications in hearing device evaluations.

Invited Recorded Talk

1529: FROM RECIPIENT EXPERIENCE TO FUNDAMENTAL MEASUREMENT: DEVELOPING A NEW PATIENT-REPORTED OUTCOME MEASURE OF PERCEIVED LISTENING EFFORT

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Background/Aims: The complexity of listening effort and its underlying mechanisms is well-established and the challenges this complexity presents for measurement are similarly well-recognised. This presentation describes the development and validation of the Listening Effort Questionnaire-Cochlear Implant (LEQ-CI), a new patient-reported outcome measure (PROM) of perceived listening effort for use with adult cochlear implant recipients. This research illustrates how the application of modern psychometric methods can: 1) provide theoretical insights into listening effort and 2) produce self-report instruments that satisfy the requirements for fundamental measurement (additive, conjoint measurement leading to interval scales).

Methods: Development and validation of the LEQ-CI proceeded according to international, consensus-based guidance and involved multiple stages: 1) a qualitative study with adult cochlear implant recipients to construct a conceptual framework for measurement; 2) an iterative process of instrument construction and refinement; and 3) initial psychometric evaluation within a Rasch measurement framework.

Outcomes: Grounded theory methods were applied to focus group (n = 17) and postal survey (n = 108) data to yield a conceptual framework for measurement that included three qualitative domains of listening effort and motivation. Instrument construction and iterative refinements produced a 21-item version of the LEQ-CI that underwent psychometric evaluation in a multi-centre field test (n = 330). The LEQ-CI was found to satisfy the Rasch model requirements for fundamental measurement, enabling the construction of an interval scale of perceived listening effort through Rasch transformation of the ordinal raw scores. Dimensionality analyses suggested motivational concepts (social connectedness, pleasure, effort-reward balance) to be components of perceived listening effort in daily life, consistent with the theoretical Framework for Understanding Effortful Listening (FUEL).

Conclusions: The LEQ-CI is the first PROM to be developed specifically for the measurement of perceived listening effort in daily life. It has potential for use both in research and clinical settings. The process of PROM development enabled a richer understanding of effortful listening in cochlear implantation whilst the use of Rasch analysis rendered the LEQ-CI suitable for co-calibration with performance outcome measures purported to index listening effort. Further validation of the LEQ-CI is planned.

Featured Recorded Talk:

1363: EFFECT OF CHRONOLOGICAL AGE ON PULSE RATE DISCRIMINATION IN ADULT COCHLEAR-IMPLANT USERS

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Temporal processing, related to pitch perception, is important for music and speech processing. Cochlear-implant (CI) users rely heavily on temporal cues for perceptual tasks, and their ability to use temporal pitch cues may be limited. Many CI users find it difficult to discriminate small changes in electrical pulse rate relative to baseline rates beyond 200 to 300 pulses per second (pps). Mechanisms underlying CI users' limited ability in discriminating pulse rate changes remain unclear, with potential contributions from peripheral and central auditory factors. Aging is associated with degradation at peripheral and central auditory levels, which may lead to declines in temporal processing abilities of older adult CI users. To date, however, it remains unknown whether aging influences CI users' ability to discriminate pulse rate changes. Therefore, this study aims to determine the influence of chronological age on pulse rate discrimination abilities in adult CI users and examine the contributions of peripheral auditory factors to pulse rate discrimination changes with advancing age.

Younger to older adult CI users (N = 20; 23 to 80 years, at least two participants per decade) took part in an electrical pulse-rate discrimination task. Participants attempted to discriminate a 35% increment in the pulse rate of electric pulse trains at a single electrode using direct stimulation. The baseline pulse rates included 100, 200, 300, 400, and 500 pps. Testing was conducted on three electrodes spanning the length of the electrode array: Electrodes 4 (basal), 12 (middle), and 20 (apical). Peripheral neural survival was estimated using the amplitude growth functions of electrically evoked compound action potentials (ECAPs) recorded at each of the three electrodes.

Results showed that advancing age was associated with lower accuracy in discriminating pulse changes at higher baseline pulse rates (e.g., 500 pps) relative to lower baseline rates. Such age-related findings persisted after accounting for the contributions from the measures of ECAP amplitude growth functions.

In summary, these results indicate that temporal pulse rate discrimination ability in adult CI users appears to decline with advancing age, especially for higher pulse rates. Such age-related declines in pulse rate discrimination appear to be related to central changes with aging. Practically, these results suggest that older CI users may receive reduced benefits from CI stimulation strategies designed to convey temporal pitch cues with variable pulse rates.

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1317: CORTICAL AUDITORY EVOKED POTENTIALS TO FREQUENCY CHANGES IN ADULT COCHLEAR IMPLANT USERS

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One of the biggest challenges for cochlear implant (CI) recipients is that the hearing outcome of implantation varies substantially across patients. As speech perception requires the ability to detect various acoustic changes (eg., frequency, intensity, timing) in speech sounds, it is critical to examine how the brain responds to within-stimulus acoustic changes in CI users. The primary objective of this study was to examine the cortical auditory evoked potentials (CAEPs) in response to within-stimulus frequency changes, or the acoustic change complex (ACC), in adult CI users. The secondary objective was to examine the correlations among the neurophysiological measures, speech outcomes, and demographics factors.

Twenty-one adult CI users (29 individual CI ears) were tested with psychoacoustic frequency change detection tasks, Consonant Nucleus Consonant (CNC) word recognition test, AzBio sentence recognition test in quiet and noise (AzBio-Q and AzBio-N), and the Digit-in-Noise (DIN test), and electroencephalographic (EEG) recordings. The stimuli for the psychoacoustic and EEG recordings were pure tones at 3 different base frequencies (0.25, 1, and 4 kHz) that contain a smooth frequency change (Δf) in at the midpoint of the tone.

Results showed that the ACC N1' latency and P2' latency did not differ across frequencies. N1'-P2 amplitude was significantly larger for 0.25 kHz than for other base frequencies($p<0.05$). The mean N1' latency across 3 base frequencies was significantly correlated to the mean FCDT, and speech scores assessed with the CNC, AzBio-Q, and DIN tests ($p<0.05$). While the duration of CI use and duration of deafness were two major demographic factors accounting for the variability in speech performance ($p<0.05$), they cannot be used to explain the variability in ACC measures. Using the criterion of 10% for the mean FCDT, the CI ears were separated into good (n=21) and poor (n=8) CI ears. Good CI ears showed a shorter N1' latency compare to the poor CI ears ($p<0.05$). The mean speech performance in good CI ears was much better in all tests than poor CI ears (65% vs. 18.5% for CNC, 78.2% vs. 25.9% for AzBio-Q, 54.5% vs. 16.5% for AzBio-N, and 3.9 dB vs. 12.5 dB for DIN). The current data showed that CI hearing outcomes can be predicted to some degree by the major demographic factors (duration of CI use and duration of deafness), easily evaluated using the simple FCDT task, and objectively assessed with the ACC.

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1322: Gjb2 DEAFNESS MOUSE MODEL FOR RESEARCH ON COCHLEAR HEALTH AND COCHLEAR IMPLANT FUNCTION

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Background: Pathogenic variants in GJB2, the gene encoding the gap junction protein connexin 26 (Cx26), are the most common cause of autosomal recessive hereditary deafness. GJB2-related deafness typically presents with moderate to severe hearing loss which in many cases does not progress, but in some it does worsen with age. Individuals with GJB2-related deafness typically perform well with cochlear implants, because auditory neurons appear to survive and function. However, in some cases, outcomes are sub-optimal. Better understanding of cochlear implant function in individuals with GJB2-related deafness could potentially improve outcomes in patients with suboptimal performance. Animal models for GJB2-related deafness are likely to be useful for designing therapies to enhance implant function.

Traditional mouse models for GJB2-related deafness have exhibited progressive and profound hearing loss associated with rapid degeneration of spiral ganglion neurons, precluding their use for testing cochlear implants. GJB2 is highly expressed in supporting cells of the auditory epithelium. Here we tested the hypothesis that inducible conditional deletion of Gjb2 in supporting cells of the mouse auditory epithelium would result in milder and non-progressive hearing loss. We further predicted that these mice could serve as a model for testing and improving the benefits of cochlear implantation in GJB2-related deafness.

Methods: We bred Sox10iCreERT2 mice with Gjb2flox/flox mice to generate Sox10iCreERT2;Gjb2flox/flox (inducible conditional knock out, iCKO) and Sox10iCreERT2;Gjb2flox/+ (conditional heterozygous control) mice. We confirmed Cre expression in supporting cells in and around the organ of Corti. We then injected tamoxifen (to activate deletion of Gjb2) in groups of mice that were either 1 or 14 days old and assessed ABR thresholds (12 and 24 kHz) and endocochlear potential 2 or 3 weeks later. Histological analysis of hair cells and spiral ganglion neurons was performed on these animals as well as other groups that survived 2 or 4 months after tamoxifen injection.

Results: The level of Cx26 in the auditory epithelium was markedly reduced in iCKO mice. ABR audiometry revealed threshold shifts at both test frequencies and that endocochlear potentials were significantly reduced in iCKO mice. Most hair cells and spiral ganglion neurons survived for about 2 months in iCKO mice, but started to gradually degenerate thereafter.

Conclusions: The 2-month time period after injecting tamoxifen, during which hair cells and neurons survive, provides a window opportunity to develop therapies that could improve outcomes of cochlear implantation for GJB2-related deafness. These iCKO mice will also be useful for determining whether electrical stimulation would slow down the degeneration of auditory neurons.

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1329: FIBROSIS ON COCHLEAR IMPLANTS: COMPLEX IMPEDANCE AS A POTENTIAL MARKER?

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Cochlear implantation induces an inflammatory response leading to fibrosis formation around the electrode array, which in some cases leads to soft failure (Seyyedi et al. 2014, Foggia et al. 2019, Hough et al. 2021). Histopathology studies of the implanted cochlea show a wide variation of severity, from mild fibrosis, with a fibrous sheath formation around the electrode array, to neo-ossification and granuloma formation (Fayad et al. 2009, Seyyedi et al. 2014, Kamakura et al. 2016, Ishai et al. 2017). Apart from severe neo-ossification, the consequences of this inflammatory response are not visible on imaging. Clinically measurable contact 'impedances' have been positively correlated with fibrosis formation in animal studies, but an increase in contact impedance can be non-specific with respect to fibrosis formed (Paasche et al. 2006, Chen et al. 2014, Wilk et al. 2016). Fibroblastic cell cultures are known to produce a fibrous extracellular matrix that can simulate the fibrotic wound-healing response that is observed in-vivo (Wong et al. 2007, Kendall et al. 2014). The goal of this study is to investigate complex impedance as a possible marker for fibrosis formation in a simplified in-vitro model of the fibrous sheath around the electrode array.

Human fibroblasts (telomerase-immortalized fibroblasts) were cultured in a fibrin gel, cast around MED-EL FLEX electrode arrays. Six electrode arrays were placed in a conical tube with a 3-plated ground electrode in cell culture media. To promote cell fibroblast contraction, TGF-β1 (10ng/ml) was added to the cell culture media on day 2. On 3 of the 6 electrode arrays, two-electrode impedance spectroscopy (EIS) with 10Hz – 100kHz sine sweeps was measured every 2-3 days out to 14 days. Following EIS, full voltage waveforms were recorded with monopolar biphasic charge-balanced current pulses at the same timepoints.

The fibroblasts contracted the fibrin gel over the experimental period, forming a dense capsule around the implant. EIS showed an increase in impedance at higher frequencies (>10kHz) over time for the electrodes under gel. A decrease in phase angle was associated with an increase in impedance, suggesting an increase in bulk resistance. The peaks of voltage waveforms, used to measure clinical contact 'impedance', increased over time. The peak of the second phase of the voltage waveform response became more balanced with the first phase, in line with an increase in the ratio of bulk resistance versus capacitance.

This study shows a consistent change in complex impedance over time with a simplified in-vitro model of the fibrous sheath around a cochlear implant electrode array, and shows potential as a detection tool of fibrosis formation and its progression. Further work will include modelling of a representative electrical circuit to the EIS and voltage waveform data, and biochemical analysis of the gel including histology, confocal imaging and DNA and hydroxyproline assays.

1340: ANALYSIS OF A COCHLEAR IMPLANT DATABASE: CHANGES IN TINNITUS DISTRESS AFTER COCHLEAR IMPLANTATION

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Objective: Whilst several studies show a reduction in tinnitus distress following cochlear implantation, others show an increase or no change after implantation. At this stage, clinicians have little certainty when counselling their patients regarding tinnitus prior to implantation. The study aims to estimate the prevalence and severity of tinnitus pre- and post-implantation in patients with bilateral severe to profound hearing loss.

Method: The study used data from a cochlear implant clinic in Perth, Western Australia. Retrospective pre- and post-cochlear implantation data from 300 implants recipients between 2001 to 2017 were collected: self-reported tinnitus, tinnitus distress using Tinnitus Reaction Questionnaire (TRQ), hearing related quality of life using the Abbreviated Profile of Hearing Aid Benefit (APHAB), and consonant-nucleus vowel-consonant (CNC) word recognition test scores. Patients were grouped into those with or without tinnitus, and the severity of tinnitus. The course of tinnitus and its severity from pre- to post-implantation was described. The potential factors associated with changes in the presence of tinnitus and its severity were evaluated.

Results: After implantation, 27 (28.1%) of the 96 patients with tinnitus pre-implantation had total suppression. 18.4% (14/76) of patients not reporting tinnitus prior to implantation reported tinnitus after implantation. Statistical analysis revealed that age at implantation (tinnitus group: 61.3 years (IQR: 47.7-72.0); no tinnitus group: 68.2 years (IQR: 57.3-76.2); p=0.002) and pre-operative pure tone average in the implanted ear (tinnitus group: 93.1 dB PTA (IQR: 78.4-102.8); no tinnitus group: 96.2 dB PTA (IQR: 85.0-107.8); p=0.038) and non-implanted ear (tinnitus group: 70.0 dB PTA (IQR: 46.9-85.0); no tinnitus group: 80.0 dB PTA (IQR: 66.6-91.2); p=0.002) were discriminant factors between the tinnitus group and the non-tinnitus group after implantation.

Conclusion: Tinnitus prevalence was 55.8% pre-operatively and 44.3% post-implantation. Tinnitus post-implantation is associated with younger age and less severe hearing loss. Improvement in tinnitus severity grade was observed in 44 (28.9%) cases comparing pre-implantation versus post-implantation. No common predictive factor was found between our results and recent literature. Further research is needed to understand the factors influencing changes in tinnitus.

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1370: SURVEY OF CURRENT ELECTRODE DEACTIVATION PATTERNS BY COCHLEAR IMPLANT AUDIOLOGISTS

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While cochlear implant outcomes have improved since early cochlear implantation, speech perceptions abilities among individual users are highly variable. Hemmingson and Messersmith (2018) identified factors which are associated with variable outcomes for pediatric and adult cochlear implant users. These include, but are not limited to, onset and duration of hearing loss, cognitive abilities, socioeconomic status, motivation, quality of care, and physiological differences. The speech processor must also be properly fit and managed by a trained audiologist, leaving much of the patient's potential to the audiologist's ability to create an appropriate program. Cochlear implant audiologists are inconsistent in their methods of programming, as reported in an international survey conducted in 2014 by Vaerenberg and colleagues. In this study, audiologists stated that the number of electrodes is changed on exceptional occasions and done so primarily if there is poor impedance, if the electrode has migrated outside of the cochlea, or if there are other non-auditory percepts occurring. Deactivating electrodes was almost never done based on tonotopic tests such as a pitch perception task or speech perception capabilities. Despite evidence to suggest that deactivating electrodes based on a pitch perception task has proved beneficial for speech perception, Vaerenberg highlights that this situation is "reported to occur almost never" (Vaerenberg et al., 2014).

Researchers have agreed that it is not necessary for all available electrodes to be active for recipients to achieve adequate speech perception (Zwolan et. al., 1997, Friesen et. al., 2001). Given the expanding body of literature focused on selective electrode deactivation and its effects on speech perception abilities (Zwolan et. al., 1997, Gifford et. al., 2017, Debruyne et. al., 2020 Schyartz-Leyzac et. al., 2017), there is a need to develop standardized, clinically relevant guidelines for deactivation. The purpose of the current survey was to quantify the degree to which practicing audiologists believe selective electrode deactivation could lead to improved speech perception outcomes. Our aim was to understand, from a clinical audiologist's perspective, the professional viewpoints regarding selective electrode deactivation to establish the need for a clinical protocol to identify poorly encoding electrodes.

The survey was distributed to both pediatric and adult audiologists who are currently licensed in the United States. Analysis of 53 responses indicates audiologists either strongly believe (39%) or generally believe (61%) that selectively deactivating electrodes with poor pitch resolution could improve speech perception outcomes for cochlear implant users. Despite these findings, only 66% reported using some measure to identify these electrodes to deactivate, and 34% reported they do not deactivate electrodes for the specific purpose of improving speech perception. Respondents were asked to elaborate on this answer. Among those who reported not deactivating electrodes for this purpose, common reasoning included "lack of evidence" and "not knowing which to deactivate." For those who reported deactivating electrodes for the purpose of improving speech perception, there was little to no consistency in the methods being used to identify which electrodes to deactivate. Our results are in agreement with previous literature that found cochlear implant audiologists are overwhelmingly in agreement that selective electrode deactivation could improve speech perception but are inconsistent in their programming methods, thus providing evidence to support the development of a clinical protocol to identify poorly encoding electrodes.

1379: HEARING PRESERVATION, ADVANCED IMAGING AND SPEECH PERCEPTION OUTCOMES WITH THE SLIMJ ELECTRODE

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Introduction
Many of today‘s Cochlear Implant (CI) candidates have significant residual hearing, which can be preserved often by usage of atraumatic electrodes and insertion techniques.
The objective of this analysis was to investigate possible correlations of hearing preservation, electrode position and speech comprehension.

Material and Methods
46 subjects with residual hearing were implanted with the HiFocus SlimJ electrode and assistance of ECochG measurements by the Advanced Bionics ECochG research system. Pure tone thresholds were assessed before and at several time points after the surgery. Pre- and post-operative CT scans were analyzed using a research software from Advanced Bionics to analyze the position of the electrode in 3D. The software uses an active shape model which allows to determine the location relative to the basilar membrane and osseous spiral lamina with an error of 0.07 mm.

Results
The HiFocus SlimJ was successfully inserted in all cases through the round window with a mean insertion angle of 374° from the round window whereby the insertion of the SlimJ was guided by the amplitude change of the ECochG signal. At one month post-op in 80% of the CI users hearing loss of less than 30dB was measured, in another 40% less than 15dB. In 40 patients a 3D model of the cochlea and the inserted electrode array has been created, showing no translocations and five arrays with potential contact to the basilar membrane. Long-term hearing preservation is currently still collected and its correlation to the imaging results will be investigated.

Conclusion
The use of ECochG to guide the insertion of the HiFocus SlimJ electrode array to reduce intracochlear trauma has shown promising results. Using an advanced imaging research software to evaluate post-OP CT images, the electrode array has shown excellent atraumatic behavior. Hearing preservation data show promising results reaching 80% complete preservation after 1 month and will be further monitored.

1384: INDIVIDUALIZED COCHLEAR IMPLANTATION- PATIENT SPECIFIC ELECTRODE SELECTION SUPPORTED BY STATISTICAL MODELS

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Aim:
Individualized Cochlear Implantation - meaning an individual selection of electrode insertion depth and stimulation modality (electric-acoustic stimulation (EAS) or electric stimulation (ES)) - aims for the best possible hearing outcome for every patient.
Important factors to be considered are hearing preservation and an optimal cochlear coverage. Shorter electrodes show better hearing preservation and very good speech perception results in EAS. Longer electrodes show a higher cochlear coverage and better speech perception results in ES but worse hearing preservation results. The concept of partial insertion could overcome this trade-off. If a longer electrode is partially inserted for EAS, it gives the option for a further adaption for ES in case of progressive hearing loss.

Material and Methods:
Statistical analysis of the audiometry and geometry database for the Medical School were performed to develop models for the prediction of postoperative residual hearing and the electrode location in a patient specific cochlea. These models were integrated into a software tool, which visualizes the estimated postoperative residual hearing and predicted electrode position and supports the surgeon with the selection of an individual electrode insertion depth. In total, n=48 patients were treated with an individual partial insertion using longer electrodes of 24 mm – 31 mm lengths. In n=21 patients the software tool was used.

Results:
The median hearing loss at first activation was 13 dB (n=15) for a partially inserted electrode of 24 mm length and 16 dB (n=21) for a partially inserted electrode of 28 mm length. The median hearing loss improved to 12 dB for a partially inserted 24 mm long electrode and to 13 dB for a 28 mm long at 6 months. N=33 patients used their low-frequency hearing for EAS and achieved in median 85% with the HSM sentence test in noise at 10 dB SNR at 6 months. In three cases, where the patients could not use the residual hearing for EAS, a successful afterloading of the electrode was performed, which offers the patient full cochlear coverage for ES-only.

Conclusion:
The concept of individualized cochlear implantation allows for a patient specific choice of electrode insertion depth and modality. Taking cochlear geometry and the prediction of postoperative residual hearing into account, an optimal cochlear coverage, best possible hearing preservation results and the best individual outcomes can be achieved. Patients treated with partial insertion can benefit from an individualized selection of insertion depth and show excellent results in EAS. If hearing is progressive over time, partial insertion allows for further, patient specific adaptation of the insertion depth

1391: YEARS OF SPECIAL EDUCATION REQUIRED BY STUDENTS WHO ARE DEAF OR HARD OF HEARING WITH COCHLEAR IMPLANTS COMPARED TO AMPLIFICATION: PRELIMINARY RESULTS FROM A PRIMARY SCHOOL COHORT

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INTRODUCTION. The Individuals with Disabilities Education Act (IDEA) mandates the provision of individualized special education and related services (SpEd) to students with disabilities. Many students who are D/deaf or hard of hearing (D/HH) rely on SpEd in order to achieve education outcomes comparable to the general population. SpEd costs approximately twice as much as general education (GenEd). Regional studies in the United States demonstrate that children with severe to profound hearing loss with cochlear implants (CIs) may require less SpEd than audiometrically-similar children with hearing amplification (HA). This study aims to evaluate whether this remains the case among the national population of D/HH students in SpEd. We hypothesize that students with CIs will spend less time in SpEd overall, though may require more time in SpEd initially, due to a steeper learning curve for speech and language development among CI users.

METHODS. This is a secondary analysis of the Special Education Elementary Longitudinal Study (SEELS). SEELS enrolled primary school students ages 6-12 years old in 2000 and followed them through 2005. The study employed a two-stage stratified sampling process to generate nationally representative samples for each disability category. We included children with a district-reported disability of “hearing impairment” and a parent-reported CI or HA with severe to profound un-aided loss. We weighted the data to generate national estimates. We are currently performing multiple imputation and building regression models for an adjusted analysis of whether there is a difference in time until declassification, or moving from SpEd to GenEd, between the CI group and the HA group. Model building is being guided by a directed acyclic graph (Figure 1).

RESULTS. There were a total of 14,3450 children who met the inclusion criteria, of whom 3,230 were classified as having cochlear implants (CI) whereas 11,120 were classified as having hearing amplification (HA)(Table 1). At enrollment, Woodcock-Johnson III scores and demographics appeared grossly similar between groups, with the exception of more of the HA group being from a lower household income bracket and a lower general health status. Over 6 years, 6.3% of the CI group and 10.3% of the HA group declassified. More than half of each group received early intervention services (CI 56.1%; HA 55.0%) and were in SpEd during preschool (CI 74.5%; HA 73.4%). The total number of years spent in SpEd among students who declassified during the study period appears to be similar between groups, though there may be a small left shift in the CI group (Figure 2).

DISCUSSION. The NCES longitudinal SpEd studies lend population-level insight into the general service requirements and educational outcomes of D/HH students in SpEd. Understanding how these requirements and outcomes vary by intervention are integral to guiding family counseling for clinical management as well as for local public policy and resource allocation. Several important confounders are unable to be controlled completely in this analysis limiting the conclusions that can be drawn. Future NCES studies should include a few key clinical variables (onset of hearing loss, age at diagnosis, etiology, course, device utilization, etc.) that would provide insight into the unique service needs and educational outcomes of D/HH students using different means of communication and devices. Future directions for this study include a multivariable regression analysis and performing the same analysis among cohorts of pre-school and secondary school students. We will state limitations clearly and carefully and emphasize the importance of combining educational and clinical variables in order to replicate the causal pathway in a statistically valid fashion.

1415: ABNORMAL IMPEDANCES AND DECREASED BENEFIT IN COCHLEAR IMPLANTS: AN ANALYSIS OF MEDICAL DEVICE REPORTING IN COCHLEAR IMPLANT LISTENERS

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Impedance measurement is routinely performed in clinical and research settings when using direct stimulation for psychophysical tasks in cochlear implant (CI) listeners. Abnormal impedance values may be observed in isolation, or with a concomitant decrease in benefit (e.g., poorer performance, no sound, poor loudness growth) with the device. In some cases, abnormal impedances may be indicative of device-related issues that lead to shortened implant life and revision/explant surgery. Device-related issues are reported and received by the FDA from different sources, including mandatory reporting entities such as device manufacturers, importers and user facilities and voluntary reporters such as clinicians and patients. Medical device reports (MDRs) analysis may reveal device associated trends that may reflect potential safety signals. MDRs provide information including, but not limited to patient age, patient sex, type of implant, event description of the clinical issue and in most cases, the patient outcome and whether actions were taken by the clinician or manufacturer. The initial clinical observation and outcome of the event may reveal trends in impedance-related perceptual changes and rates of explantation in these events. This analysis was conducted to describe the extent to which impedance changes are reported as a medical device issue and to categorize the type and range of clinical issues observed and the outcome, if any. MDRs for cochlear implants submitted between January 1st, 2016 and March 11th, 2021 (~5 years) were retrieved from the Manufacturer and User Facility Device Experience (MAUDE) database for analysis. Duplicate CI serial numbers were removed, as well as cases with reference to “normal impedance(s).”Out of 18363 MDRs, 722 referenced “impedance” (abnormal or high) in the event description (about 3.9% total), with 2016 and 2020 showing the highest rate of impedance-related MDRs. Patient age was available for 584 cases, ranging from 0.9 to 92 years of age (Mean = 25.1 years, Median = 7.9 years, SE = 1.17). Several “clinical issue” and “outcome” categories were further categorized based on the event description. Of these 722 impedance-related MDRs, 357 referred to abnormal impedance only (49.45%), 322 coincided with decreased benefit (44.6%), 43 (5.96%) referred to high impedances after trauma. For the outcome category, abnormal impedances resulted in revision/explant in 551 cases (76.32%), is ongoing/unresolved for 116 cases (16.07%), unknown for 31 cases (4.29%), resolved with medical treatment (e.g., oral antibiotics) for 10 cases (1.39%), resolved with re-programming for 10 cases (1.39%), and 4 cases were considered resolved without additional detail provided (.55%). Of the clinical issues categorized, abnormal impedance only and decreased benefit secondary to abnormal impedance were the most predominant, with revision or explant surgery the most common outcome. These issues were pre-dominant in children under the age of 10, with fairly even distribution across the rest of the age-range. When conducting psychophysical tasks under direct stimulation, awareness of observed spikes in impedance values, patterns, or quality of sound may be indicative of a device-related issue that could alter task results. It is important to note abnormal impedance changes, whether or not device benefit is impacted, and report to the CI audiologist or manufacturer if these changes persist.

1418: INVESTIGATION OF INFLUENTIAL FACTORS ON THE RELATIONSHIP BETWEEN SPEECH RECOGNITION AND COCHLEAR HEALTH MEASURES

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One potential reason behind the high variability in cochlear implant (CI) users' speech recognition is the inter-individual variation in the number and/or the functionality of spiral ganglion neurons (SGNs) and other parts of the neural substrate, i.e. the cochlear health. There is evidence showing a correlation between speech reception thresholds (SRT) and cochlear health (Schvartz-Leyzac and Pfingst, 2018) for a particular artifact reduction method. However, the influential factors determining the extent of such a correlation have not yet been fully identified. The aim of this study was to investigate the influence of the ECAP artifact reduction method, electrode impedances and the speech band importance function on the relationship between such cochlear health measurements and speech intelligibility.

A group of 13 bilaterally implanted subjects were included in the study. To estimate cochlear health, the change in the slope of the ECAP amplitude growth function (AGF) following an increase in the interphase gap (IPG) in a biphasic stimulus from 2.1 µs to 30 µs was measured and defined as the IPG effect (IPGE) on slope, with larger IPGEs indicating better cochlear health (Prado-Guitierrez et al., 2006 & Ramekers et al., 2014). For ECAP measurements, three different artifact reduction methods were used: The forward masking paradigm with 1) anodic leading (FMA) and with 2) cathodic leading (FMC) pulses and 3) using an alternating polarity (AP) approach for artifact reduction. The relative importance of each frequency band for speech intelligibility in noise coded by SGNs in different cochlear regions was taken into account by applying a weighting function (ANSI, 1997) to the measured IPGE on slope according to each electrode contact position in the cochlea. Inter-subject variation in terms of central auditory system processing ability was controlled by using the magnitude of the between ear difference of the cochlear-wide mean of the IPGE and the magnitude of the between ear difference of SRT for each subject (Schvartz-Leyzac and Pfingst, 2018) for the outcome measure.

The results showed a significant correlation among the between ear difference in IPGE on slope and the between ear difference in SRT for the paradigm AP after applying the speech band importance weighting function. Subjects with higher mean IPGE on slope values also showed better SRTs. On the group level, no correlation was observed between IPGE on slope and electrode impedance. However, investigation of individual ears showed both significant positive and negative correlations between IPGE on slope and impedance for a few cases. Exclusion of subjects with a negative correlation between IPGE on slope and electrode impedance resulted in stronger correlation among between ear difference of IPGE and of SRT for paradigm AP and a marginally significant correlation for the paradigm FMA. In none of the conditions was a significant correlation observed for FMC.

This study showed that CI users' speech intelligibility in noise is related to this cochlear health estimate. To model this relationship, it is necessary to apply a speech importance weighting function that takes into account the information in different frequency bands, conveyed by SGNs in different cochlear regions. The observed stronger correlation for alternating pulses in comparison to the forward masking approach might be due to fewer missing data points in the AP condition. Electrode impedances might, for some individual cases, restrict the potential of cochlear health measures to predict the SRT. However, further investigation is required to decisively conclude this matter.

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1427: VALIDATING A PATIENT-SPECIFIC 3D-PRINTED MODEL OF COCHLEAR MALFORMATIONS

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Background
Radiologically evident inner ear malformations represent approximately 10-20% of patients with congenital hearing loss. Cochlear malformations are difficult to model on a patient-specific basis due to poor accessibility of the inner ear, rarity of cadaveric specimens, and the lack of suitable in vitro or in vivo models. Thus, this project aims to reliably reconstruct and validate a 3D-printed model of cochlear malformation to be used as a testbed to evaluate cochlear implant (CI) current spread and different stimulating strategies.

Methods
Segmentation methods of clinical CT were compared for accuracy of three types of cochlear malformation: incomplete partition I, II and III. The cochleae were printed at a 30-micron voxel resolution using a digital light processing (DLP) 3D printer to create 3D-printed biomimetic cochleae. 3D-printed cochleae were flushed with 1% saline and a CI522 cochlear implant was inserted. The conductivity of the models was adjusted to replicate the conductivity of bone by introducing a network of saline microchannels of varying diameters and spacing to mimic patient-specific transimpedance matrices.

Results
Three types of cochlear malformations were reconstructed by fitting the template surface of a normal cochlea to clinical CT data, using a local affine deformation. The segmentation was manually reviewed and edited to reflect the cochlear malformation. This produced more accurate reconstructions than traditional threshold segmentation. The DLP printer produced highly accurate transparent prints, enabling visualisation of implant insertion and positioning, which is important for assessing anomalous location and, for instance, tip fold-over. Following cochlear implant insertion, there was a negative correlation between porosity (i.e., number of diameter of pores) and voltage.

Conclusion
This process allows on-demand printing of patient-specific cochlear malformations with properties matching those of human inner ear malformations. This model will enable insertion of recording electrodes, where neural tissue resides, to measure voltage distribution in the simulated nerve using different implant types and stimulating strategies. As we move towards personalised medicine, this setup could lead to pre-operative rehearsal of stimulating strategies and choice of implant, as well as testing better stimulating strategies for poorly performing existing patients.

1434: MORPHOLOGICAL CHANGES OF THE ELECTRICALLY EVOKED COMPOUND ACTION POTENTIAL FOLLOWING OTOTOXIC DEAFENING IN CHRONICALLY IMPLANTED GUINEA PIGS

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Secondary to severe hair cell loss, the spiral ganglion cells (SGCs) that comprise the auditory nerve degenerate progressively. Using electrically evoked compound action potentials (eCAPs), we have previously shown that this structural degeneration is accompanied by functional changes in deafened guinea pigs (e.g., Ramekers et al., 2014, J Assoc Res Otolaryngol). While previously focusing on the eCAP N1 peak amplitude, in the present study we examine changes in the morphology of the eCAP after ototoxic deafening.

Ten normal-hearing guinea pigs were implanted with an intracochlear electrode array (MED-EL, Innsbruck, Austria). Four weeks after implantation the animals were deafened by co-administration of kanamycin and furosemide. Using a MED-EL PULSAR cochlear implant, awake eCAP recordings were performed at least weekly for eleven weeks following implantation. Following the final eCAP recording session the animals were sacrificed, and their cochleas were processed for histological quantification of SGCs.

During the first four weeks after implantation, along with a slight increase of its amplitude, the eCAP N1 peak became significantly narrower, and accordingly the peak area remained relatively stable. Combined with the observation that the N1 latency decreased, this suggests that over time after implantation firing synchronicity of the SGC population had increased, or, alternatively, that the shape of the unit response (Strahl et al., 2016, Adv Exp Med Biol) had changed. Within days after deafening the peak width had decreased by approximately 20%, which recovered and remained at normal-hearing values after two weeks. The peak area followed the same pattern in the first week after deafening, but then along with the amplitude substantially decreased, largely reflecting SGC loss.

We conclude that additional information about auditory nerve function can be derived from the eCAP by analyzing the eCAP morphology. Specifically, measures of firing synchronicity can be informative in themselves, but can also be used to better understand the traditionally used eCAP measures such as peak amplitude, threshold or latency.

1477: NEURAL HEALTH CHANGES AFTER COCHLEAR IMPLANTATION IN PATIENTS WITH RESIDUAL HEARING

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While cochlear implants have been successful in treating many patients with severe-profound hearing loss, there remains significant variability in outcomes. One potential factor in this variability is the health of the auditory nerve. Components of the auditory nerve that may determine functionality of electric stimulation include the spiral ganglion cells, peripheral neurites, and myelination. Certainly, pre-operative neural health is likely to be important, as long duration of deafness has been associated with both poorer outcomes and poorer nerve survival. Conversely, could post-operative changes in neural health also contribute to variability in outcomes?

Here we describe preliminary findings from a study investigating post-operative changes in neural health over time following cochlear implantation, with a focus on patients with low-frequency residual hearing. Three adult CI patients (2 Cochlear, 1 Med-El) were recruited prior to surgery, and tested at various time points post-surgery, from initial activation to up to 12 months. Pre- and postoperative audiograms, monopolar thresholds and comfortable stimulation levels, and impedance measures were collected. Neural health was assessed using two measures 1) the electrically-evoked compound action potential (ECAP) inter-pulse gap (IPG) effect; and 2) the polarity effect (PE). ECAP amplitude growth functions were measured for two inter-pulse gaps (IPGs), 8-10 and 30 microseconds, in order to measure the IPG slope and offset effects. ECAP measures have been shown to correlate with spiral ganglion neuron survival in animal models (Ramekers et al., 2014), and are more independent of electrode-modiolar distance than slope alone (Brochier et al., 2021; Schvartz-Leyzac et al., 2020). The PE was measured as the difference in threshold between mainly positive (anodic) and mainly negative (cathodic) triphasic pulse trains, with thresholds for each measured psychophysically using a three-alternative forced choice procedure (e.g. Macherey et al., 2017; Jahn and Arenberg, 2019). Neural modeling studies suggest that the size of the PE indicates peripheral neurite survival and/or myelination (Rattay et al., 2001; Resnick et al., 2018). Electrocochleography (EcochG) was also obtained in Cochlear patients to objectively assess hair cell survival and auditory nerve function with acoustic stimulation.

Preliminary findings indicate that ECAP and PE can change over time after implantation, and the direction of changes can vary across the electrode array and across patients. Correlations with post-operative hearing changes, EcochG results, and with cochlear implant outcomes will be presented. This research was funded by a NIH NIDCD grant R56DC018387.

1485: VOCAL EMOTION PRODUCTION OF PEDIATRIC COCHLEAR IMPLANT USERS: EFFECT OF ACOUSTIC HEARING EXPERIENCE

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Emotional communication, including both vocal emotion recognition and production, is important for social interactions, cognitive development, and quality of life. Due to the limited spectra-temporal resolution of cochlear implants (CIs), CI users may not perceive sufficient pitch cues critical for vocal emotion recognition. Deficits in perceiving pitch cues may also affect CI users' production of pitch for different emotional intents. Chatterjee et al. (2019) found that compared to age-matched normal-hearing (NH) listeners, pre-lingually deaf pediatric CI users produced less contrast in pitch between emotions, while post-lingually deaf adult CI users did not. Unlike post-lingually deaf adults, pre-lingually deaf children in the previous studies did not have access to acoustic hearing in early childhood, which may be important for the development of vocal emotion production. This study aimed to test the effect of early acoustic hearing on vocal emotion production of pre-lingually deaf children with CIs.

There were four groups of participants: 16 pre-lingually deaf pediatric CI users with documented acoustic hearing experience (either pre-implant for simultaneous bilateral CI users, or both pre- and post-implant for sequential bilateral CI and bimodal CI users), 9 post-lingually deaf adult CI users with bimodal hearing, 12 NH children, and 11 NH adults. Most participants were tested in a sound booth, while the others were tested in a quiet room at home due to the COVID-19 pandemic. After listening to examples of vocal emotion production, participants were asked to produce 10 semantically-neutral sentences with both happy and sad emotions. CI users used their clinical devices' daily settings during the task. For each sentence, mean fundamental frequency (F0), standard deviation of F0, root-mean-square intensity, and duration were extracted and checked for accuracy. Adult CI users were also tested with vocal emotion recognition.

The results showed that most participants used higher mean F0, larger F0 variation, greater intensity, and shorter duration for the happy emotion than for the sad emotion. All the acoustic features were significantly affected by emotion and sentence, but not by group. The effect of group was only significant for the contrast of intensity, but not for the contrasts of mean F0, F0 standard deviation, and duration between emotions. Pre-lingually deaf pediatric CI users showed greater contrast in intensity between emotions than the other groups. For post-lingually deaf adult CI users, the contrast of F0 standard deviation between emotions was correlated with their vocal emotion recognition score. For pre-lingually deaf pediatric CI users, the contrasts of mean F0, F0 standard deviation, and duration between emotions were all correlated with their aided threshold in the acoustic ear. These results suggest that acoustic hearing in early childhood may facilitate the development of vocal emotion production in pre-lingually deaf CI children.

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1501: EFFECT OF FREQUENCY-TO-ELECTRODE ALLOCATION MANIPULATIONS ON INTELLIGIBILITY OF SPEECH PREDICTED WITH OBJECTIVE MEASURES: ACOUSTIC SIMULATIONS OF COCHLEAR IMPLANT

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Most cochlear implant (CI) users have limited pitch resolution. One of the main reasons is the degraded temporal and frequency resolution of the stimulation pattern delivered by the CI. The Synthetic Feature eXtraction (SFX) is a new sound processing strategy designed to provide increased spectral and temporal resolution compared to the standard FFT. The increased resolution provided by SFX allows for a more detailed manipulation of the bandpass filter parameters, i.e., the filter slope, the filter bandwidth and the filter distribution. These parameters control for the selectivity and precision of frequency-to-electrode mapping. Narrower filter spacing, particularly at low frequencies, has been shown to improve performance in both music and speech related tasks. This modified assignment of the cutoff frequencies leads to more resolution in the lower frequency channels compared to the standard FFT strategy.

In this study we investigate how SFX may allow the definition of parameters settings that could achieve to an optimal CI hearing. We present different frequency-to-electrode allocations that could improve music and speech outcomes and investigate how the modified assignment of the cutoff frequencies affect speech intelligibility. We compare the SFX with the standard FFT signal processing as well as other filterbank approaches. Different objective measures are used to predict speech outcomes such as the Short-Time Speech Intelligibility (STOI), Output Signal to Noise Ratio (OSNR) and Structural Similarity Index Measure (SSIM) and their limitations and potentials are discussed. We provide statistical analysis which aims to uncover the underlying factors that contribute to the variabilities of these measures in predicting the speech performance outcomes.

A future study will use CI users' speech performance results to fine tune and validate the mapping parameters between the objective measures and patients' outcome performance in order to improve the accuracy of our predictive models. These results will potentially improve the effectiveness of sound processor research and CI fitting.

1503: CARS, ALARMS AND BABIES: IDENTIFICATION OF SAFETY-RELEVANT ENVIRONMENTAL SOUNDS BY COCHLEAR IMPLANT LISTENERS

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Assessment of cochlear implant (CI) outcomes has traditionally focused on speech perception. Perception of non-linguistic meaningful sounds, i.e. environmental sounds, in CI listeners has received considerably less attention, despite its contributions to quality of life, independence, and safety. Recent research has indicated that the performance of experienced postlingual CI listeners, as a group, does not differ from CI candidates prior to implantation, although considerable individual variation exists (McMahon et al., 2018; Harris et al., 2021). Secondary data analysis suggested the same pattern of results for a sub-category of environmental sounds, safety-relevant sounds, which are judged as especially important to individual safety and well-being (Hamel et al., 2020). The present study aims to evaluate identification accuracy of safety-relevant environmental sounds by cochlear implant listeners in comparison to other meaningful environmental sounds. A secondary goal is to examine the relationship between sounds' perceived familiarity and importance to safety and identification accuracy.

Twelve experienced postlingually implanted adult CI listeners (ages 50 – 87, at least 3 years CI use) listened to and identified 42 environmental sounds, 28 of which were defined as safety-relevant (e.g. alarms, gun shots, car honks). Test sounds were selected to be highly identifiable for normal hearing adult peers. Prior to auditory identification, participants rated each sound's familiarity and relevance to personal safety on a 5-point scale.

Consistent with prior studies, preliminary results indicate a mediocre overall identification accuracy (56%) across all sounds. No differences were observed in identification of safety-relevant and other common environmental sounds, 56% vs. 54%, respectively. Participants rated the safety-relevant sounds as more important to their safety than the rest (3.97 vs. 1.78). Safety-relevant sounds were also judged, on average, as more familiar than the non safety-relevant sounds, 4.08 vs 3.71, respectively. There were moderate correlations between familiarity ratings and identification accuracy for both safety-relevant and non safety-relevant sounds, $r = 0.466$ vs. $r = 0.576$, respectively.

The findings of the study thus far indicate that the perception of environmental sounds in general, and safety-relevant environmental sounds in particular remains a challenge for experienced CI users. More consistent inclusion of environmental sound perception in CI performance assessments combined with targeted rehabilitation may be recommended to improve CI outcomes. More research is needed to examine perception of environmental sounds in prelingual and multiply involved CI listeners, for whom environmental sound perception may be of even greater importance.

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1508: PREDICTION OF COCHLEAR IMPLANT HEARING PERFORMANCE AND PROTOTYPE OUTCOME PREDICTION TOOL

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While cochlear implantation is an efficacious treatment of severe to profound sensorineural hearing loss, there is large range of hearing outcomes with the therapy. This outcome variability limits clinicians' ability to confidently counsel candidates on the potential benefits of cochlear implantation versus other options. The objective of this study was to identify factors that influence or correlate with clinical hearing outcomes and to use these variables in predictive models. Data from two clinical studies (CRC Outcomes Prediction Study (n=117) and CI532 Benchmark Study (n=96)) were used and included pre- and post-operative tests of monosyllabic word recognition, sentence in noise understanding, audiogram, and SSQ. Patients' device settings, sound processor usage logs, and additional questionnaires were also collected. Due to the breath of the data, techniques were employed to identify a relatively small set of variables to be used in a range of statistical modelling and machine learning techniques.

Consistent with previous research, factors including age at implantation, analogues of duration of deafness, and degree of hearing loss were identified as predictive of outcomes. However, other factors identified included patients' self-assessment of psycho-social factors and hearing abilities. While not necessarily helpful for outcome prediction at the candidacy phase, correlates were also found for post-operative variables such as time on air and dynamic range of stimulation levels.

The outcome prediction models for the CRC Outcomes Study achieved a test-set RMSE for CVC score of 15.8% (mean cross fold validation R2 of 0.21) and the CI532 Benchmark Study achieved a test-set RMSE for CNC score of 13.3% (mean cross fold validation R2 of 0.25). These models were then incorporated in a prototype web app in which the user can input patient variables and view predictions, with range of certainty, of the clinical hearing improvements expected from cochlear implantation. Future work is needed assess the usability and effectiveness of such outcome prediction tools as an aid to counseling during the assessment of cochlear implant candidacy.

1515: EVALUATING AN INDIVIDUAL ANATOMY-BASED ADAPTATION OF THE FREQUENCY ALLOCATION TABLE IN CI USERS

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Cochlear implants (CIs) are usually fitted with a one-size-fits-all frequency-to-electrode allocation table (FAT). However, it has been shown that the anatomy of the cochlea (cochlear duct length, number of turns etc.) can differ substantially between patients. Consequently, the place frequency (as determined by e.g. the Greenwood model) deviates to a varying degree from the frequency band allocated to the electrode contact. Even though it is known that CI users can adapt to this “tonotopic discrepancy“, the extent of this adaptation is not quite clear and may differ from patient to patient. It is hypothesized that single-sided deaf (SSD) CI users may benefit from an FAT that is better adapted to the natural tonotopy of the normal hearing contralateral side.

Nine SSD subjects (5 female, 4 male) have finished this study so far. On average, subjects were aged 50.4 years (34 – 76 years), and the first study measurement took place 23.2 months (9 – 52 months) after cochlear implantation. All subjects had normal hearing on the contralateral side (4-PTA <= 35 dB HL) and were implanted with a MED-EL cochlear implant with FLEX28 electrode array. Preoperative cone-beam CT (CBCT) image data was used to trace the lateral wall of the cochlea, while the intracochlear location of the electrode contacts of the CI were determined in postoperative CBCT data. Then, these two measurements were registered onto each other and an individualized place-to-frequency model was applied to determine the electrode contacts’ place frequency. The FATs of the subjects were then adapted to better fit the measured place frequencies while also preserving the audio processor’s full frequency range from 70 – 8500 Hz.

We measured sentence recognition in noise, pitch matching with the contralateral side, and subjective sound quality at four appointments using an A-B-A-B scheme, with at least 4 weeks between appointments. After the base line measurement with the standard FAT (A), subjects were fitted with the experimental FAT until the next appointment (B). This cycle was then repeated.

Preliminary results show that sentence recognition scores did not change significantly during the study. While subjects on average performed accurate pitch matching with the standard FAT, pitch matching deviated by approximately a half octave when the experimental FAT was activated. Again, this behavior did not change over the course of the study. The subjective sound quality with the experimental FAT was rated quite differently between subjects. Some subjects rejected the experimental FAT altogether (mostly because sound was perceived as dull/muffled), some subjects always preferred the FAT that had been activated since the last study appointment and some subjects preferred the experimental FAT.

In conclusion, an acclimatization period of four weeks seemed to short for the subjects to adapt to the experimental FAT, which would explain why no changes in sentence recognition and pitch matching could be observed. Additionally, for some of the subjects the changes between FATs and/or the amount of adaptation to the standard FAT may have been too large, so the subjects rejected the experimental FAT based on perceived sound alone. Since the individualized FATs did not have a detrimental effect on sentence recognition, future studies may analyze if there is a benefit of individualized FATs for newly implanted CI users.

Device Technology – Invited and Featured Talks + Posters

Invited Recorded Talk

1472: TOWARDS THE OPTICAL COCHLEAR IMPLANT: OPTOGENETIC STIMULATION OF THE AUDITORY PATHWAY AND THE TRANSFECTION OF SPIRAL GANGLION NEURONS

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The Göttingen Cochlear Optogenetics Program aims to encounter the limitation of cochlear implants by replacing electrical stimulation with spatially confined optical stimulation of SGNs based on an optogenetics approach. Referring to this, recent work followed a broad range of related research from the transfection of SGNs to the technical development of optical cochlear implants (oCI).

We have successfully established the optogenetic stimulation of the auditory pathway in rodents following virus-mediated transfection of SGNs with channelrhodopsins. Fast opsins enabled SGN firing at near physiological rates and activated several stages of the auditory pathway. The spectral selectivity of the tonotopic activation as well as the stability and characteristics of microfabricated LED cochlear implants was demonstrated. Behavioral studies in rodents showed auditory percepts in response to oCI stimulation. Regarding the clinical translation, further research is needed to establish a reliable and safe transduction of mature SGNs, which were shown to be significantly less sensitive to optogenetic transduction. To avoid phototoxicity, the use of long-wavelength light should be preferred.

In summary, we demonstrated that both the optogenetic stimulation and the development of oCIs have achieved important breakthroughs. The principle of optogenetic stimulation of the auditory pathway offers a high potential for future application in hearing restoration.

Invited Recorded Talk

1351: USING HAPTIC STIMULATION TO ENHANCE AUDITORY PERCEPTION IN COCHLEAR IMPLANT USERS

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Cochlear implants (CIs) allow many users to achieve excellent speech understanding in quiet listening conditions, but most struggle to understand speech in noisy environments and to locate sounds. This talk will present our recent work showing improvements in speech-in-noise performance and sound localisation when the electrical CI signal is supplemented using haptic stimulation on the wrists (“electro-haptic stimulation”). In our first study, we provided the speech amplitude envelope through haptic stimulation, which was extracted from the speech-in-noise signal using a signal-processing approach suitable for use in real time on a compact device. After 20 mins of training, participants were found to be able to identify 8% more words in noise with electro-haptic stimulation than with their CI alone. In our second study, we extracted the speech amplitude envelope from the audio received by devices behind each ear and delivered it through haptic stimulation on each wrist. This allowed us to transfer spatial-hearing cues. The unilateral CI users in our study were shown to have substantially improved sound localisation with electro-haptic stimulation, achieving performance comparable to that of bilateral hearing-aid users. In future work, we hope to develop a compact wrist-worn device to deliver haptic stimulation to CI users in the real-world. This could have an important clinical impact, providing an inexpensive, non-invasive means to improve speech-in-noise performance and spatial hearing.

Acknowledgements
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Featured Recorded Talk:

1412: HEADPHONES OVER THE SOUND PROCESSOR FOR REMOTE CLINICAL AND RESEARCH APPLICATIONS

Joshua G.W. Bernstein, Elicia M. Pillion, Coral E. Dirks, Douglas S. Brungart, Anthony M. Tolisano
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With widespread adoption of Bluetooth technology, the availability of direct auxiliary input (DAI) to the cochlear-implant (CI) sound processor is waning. While a wireless link is clearly more convenient for the CI user, this complicates the common psychoacoustic research approach of presenting speech and other acoustic stimuli to the sound processor via DAI. As an alternative, some researchers have employed the approach of placing large circumaural headphones over the sound processor to relay acoustic information. For example, such an approach can be used to simulate spatial acoustics using head-related transfer functions (HRTFs).

This presentation will overview efforts to measure and validate the headphone-based approach for recreating a free-field sound environment for CI listeners. This effort has important applications in three different but related applications: 1) a tele-medicine initiative, with the goal of replacing clinical standard-of-care sound-field audiometric and speech-perception testing for a remotely located patient, 2) a tele-research initiative, with the goal of replacing DAI and spatial-hearing tests for bilateral and single-sided-deafness cochlear-implant users with headphone-based testing for a remotely located research participant, and 3) laboratory-based testing where headphones and HRTFs are used in place of a speaker array.

The goal of the calibration process is to reproduce via headphones the pattern of electrical stimulation and psychoacoustic test results for loudspeaker presentation. This is done by first employing virtual-audio techniques to measure impulse responses of both the loudspeaker and headphone systems for a microphone placed next to the CI sound processor. Next, CI electrodogram recordings are made using a “CI-in-a-box” and compared between the two systems, with adjustments made to the calibration filter to offset any discrepancies. Finally, the calibrated system is validated with speech perception and audiogram tests.

Electrodograms and perceptual results show that the headphone calibration is highly repeatable for low and mid-frequencies but becomes more variable above 4 kHz where headphone placement has a larger effect. Despite this variability, perceptual measures are usually consistent between the headphones and loudspeaker within 5 dB for audiometric measures and within 10 percentage points on speech-perception measures. Furthermore, the headphone calibration is similar across behind-the-ear sound processor models, such that manufacturer-specific calibration may not be required.

In summary, placing large circumaural headphones over the sound processor is a feasible approach for many laboratory and remote at-home CI clinical and research applications. Some exceptions may include precise psychophysical applications such as interaural loudness discrimination measurements at high frequencies, where sound levels are more susceptible to variability in headphone placement.

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Featured Recorded Talk:

1353: APICAL STIMULATION WITHOUT LONGER ELECTRODE ARRAYS

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Cochlear implant (CI) electrode arrays are only partially inserted into the cochlea, usually leaving more than half of the cochlea unstimulated. Extending the region stimulated by the electrode array has the potential to improve speech perception and accelerates adaptation to the device. This may be due to representation of low-frequency information closer to the normal cochlear place or improved temporal coding from the apex. However, using longer electrode arrays to access apical regions has multiple disadvantages. One is that the likelihood of an incomplete insertion increases with array length because the scala tympani diameter decreases with increasing cochlear depth. Another is the probability of damage to cochlear structures may increase deeper in the cochlea as the walls of the cochlear duct are closer to the electrode.

We developed a novel approach to stimulate the apex without increasing the electrode array length. An electrode is placed into the helicotrema (instead of the temporalis muscle) via an apical cochleostomy. Additionally, an electrode array is inserted through a basal cochleostomy. In this new configuration, stimulation from the electrode array can be grounded to the case electrode providing monopolar (MP) stimulation, whereas grounding to the helicotrema reshapes the electric field towards the apex. Additionally, stimulation in the helicotrema can be provided in MP mode by stimulating with the apical electrode and grounding with the case.

So far, three participants have received a CI with this configuration. In their clinical programs, the lowest frequency channel is mapped to the apical electrode whereas the remaining channels are presented from the electrode in MP mode. Speech perception is then evaluated with the maps including and excluding the apical ground electrode. Psychophysical measures of pitch ranking, scaling, and multi-dimensional scaling (MDS) are conducted with stimulation grounded to the case and the apex to determine the effect of the apical ground electrode on place pitch.

All patients have good speech understanding with the new approach. Pitch ranking and scaling suggests that stimulation is perceived as lower in pitch when the apical electrode is used as a ground instead of MP mode. Similarly, MDS results suggest that shifting from MP to apical ground mode shifts the percept tonotopically towards the apex. The MDS results also suggest that there were no perceptual differences between MP and apical ground modes other than a change in place pitch.

This new technique allows the use of conventional electrode arrays to stimulate deeper into the apex. To date, the procedure is safe and efficacious, and place pitch is successfully extended. Our research is continuing to determine if this configuration leads to improved results. Additionally, we are exploring the optimal fittings for the new technique and potential new signal processing implementations.

1326: VARIABILITY IN SURGICAL TECHNIQUES FOR COCHLEAR IMPLANTATION: AN INTERNATIONAL SURVEY STUDY

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Objectives: The aim of this study was to gain insight in the current practices regarding the surgical techniques used for positioning and fixation of the internal components of the cochlear implant.

Methods: In this cross-sectional study, a questionnaire was distributed among 441 cochlear implant surgeons. Questions were posed regarding the surgical techniques used for cochlear implantation, including the changes in the surgical technique during the respondents' career. Descriptive statistics were reported.

Results: The questionnaire was completed by 58 surgeons working in 13 different countries. The most preferred incision shapes were the S-shape (40%), and the C-shape (36%). The preferred implantation angle for the receiver/stimulator device was either 45° (64%) or 60° (31%), relative to the Frankfurter Horizontal Plane. The most used techniques to fixate the receiver/stimulator device were a drilled bony well (31%), a drilled bony rim with subperiosteal pocket (43%), and a subperiosteal pocket (17%). All respondents used the facial recess approach. For insertion inside the scala tympani, most respondents used the round window insertion technique (74%). Approximately half of the respondents preferred the lateral wall electrode array, whereas the other half preferred the perimodiolar electrode array. During their career, 86% changed their technique, with most changes focussing on structure preservation and minimizing trauma.

Conclusion: There is a variability in the surgical techniques used to position and fixate the internal components of the cochlear implant. Additionally, this study shows a change in surgical preference towards structure preservation and minimal invasiveness.

1327: COCHLEAR IMPLANT POSITIONING AND FIXATION USING 3D-PRINTED PATIENT SPECIFIC SURGICAL GUIDES

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Background: Positioning and fixation of the cochlear implant (CI) is commonly performed free hand. Applications of 3-dimensional (3D) technology now allow us to make patient specific, bone supported surgical guides, to aid CI surgeons in exact placement with a bony well to stabilize the implant.

Objective: To develop and validate the optimal design and evaluate accuracy of patient specific 3D printed surgical guides for cochlear implantation.

Study subjects and methods: Preoperative cone beam CT (CBCT) scans were performed on 9 cadaveric heads (18 ears), followed by virtual planning of the CI position. Surgical, bone-supported drilling guides were designed for an optimal fit and were 3D printed. Fixation screws were used to keep the guide in place during cortical embedment. Specimens were implanted with three different CI models. CBCT scans were repeated postoperatively.

Main outcome measures: Accuracy of CI placement was assessed by comparing the 3D models of the planned and implanted CI's by calculating the translational and rotational deviations.
Results: Median translational deviations of placement in the X- and Y-axis were within the predetermined clinically relevant deviation range (< 3 mm per axis). Rotational deviations of placement for X-, Y- and Z-rotation were 5.50°, 4.58° and 3.71°, respectively.

Conclusion: This study resulted in the first 3D printed, patient- and CI- model specific surgical guide for placement and fixation during cochlear implantation. Clinical implementation and evaluation of this surgical guide is intended.

1375: CAPACITIVE VERSUS CONSTANT PHASE ELEMENT MODELS IN COCHLEAR IMPLANT ELECTRODE-TISSUE INTERFACE

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Objective: To understand variation among cochlear implant electrode-tissue models and parameters available in the state-of-the-art.

Background and rationale: In cochlear implants (CI) the stimulation pulses and auditory neuronal responses may be modified at the electrode-tissue (ET) interface; therefore, proposing a good ET model and a proper parameter identification method are crucial in CI stimulation/recording optimizations. In electrochemistry studies the ET interface is mostly modeled by a faradic resistor in parallel with a constant phase element (CPE) (a fractional power capacitor). The parameters are estimated by electrochemical impedance spectroscopy (EIS) data in the frequency domain. However, in CI studies the CPE is usually substituted by a capacitor element (fractional power 'alpha' equal to 1) and the system identification is performed in time domain using short stimulation pulses. This method is fast (frequency sweeping not required), but a great deal of variation in the estimated values of the faradic resistor (from a few kΩ to MΩ), and the capacitor C (from a few nF to μF) is seen in literature. This study aimed to find out the reason for this large discrepancy observed in the literature.

Methods: Oticon Medical CI electrodes were used in this study. For a given electrode inserted in saline water, a CPE-based ET model was fitted using the EIS data in the frequency range [0.1Hz - 1MHz]. Three different RC models (first to third order) were considered as ET models. These RC models were identified in frequency and time domains, using EIS data and short current stimulation pulses (1ms), respectively.

Results: The CPE model exhibited an overall good fitting to the EIS data (Rf~=800kΩ, CPE~=6.5μF, alpha~=0.73). The first-order RC model could not fit well to the entire frequency range of EIS. When identified using the temporal method, the impedance spectrum of the model was much lower than EIS at low frequencies. Therefore, the faradic resistor was estimated much lower than its true value. This lower value estimation may vary from one study to another due to different fitting and conditioning methods.

Resulting from different capacitive fractional power values in RC and CPE models, the shapes and slopes of the impedance spectra are different, therefore varying C cannot provide a perfect match. Consequently, the estimation of C becomes a matter of choice during the fitting process that can be different from one fitting method/conditioning to another.

For the second-order RC model, when identified using the temporal fitting method, a good match could be obtained to EIS data for mid to high frequencies, but not for low frequency components. This is because of the short window length used in the temporal fitting method. Consequently, the faradic resistor could not be estimated correctly. Increasing the model order to 3 does not resolve this issue. When the second-order model was identified in frequency domain a good match to EIS and temporal data was obtained (expect the very low-amplitude fast transitions in the temporal data). In this method, the faradic resistor was correctly estimated. For the third order RC model, a perfect temporal match to EIS and temporal data was obtained thanks to three identified time-constants values about 1.3sec, 7.5ms, and 0.2ms corresponding to low, mid, and high frequencies.

Conclusions: The first-order RC model does not provide good match to the CPE model. With temporal fitting methods the faradic resistor cannot be estimated properly even after increasing the order of the model to three. A third order model can represent well EIS and temporal data if the fitting is performed in the frequency domain.

1377: A MULTI CONSTANT PHASE ELEMENT MODEL FOR THE COCHLEAR IMPLANT ELECTRODE-TISSUE INTERFACE

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Objective: To find the minimum and optimum numbers of constant phase element components needed to be integrated into a cochlear implant electrode-tissue model.

Background and rationale: It is commonly accepted that the cochlear implant (CI) electrode-tissue (ET) interface can be modeled very well using a constant phase element (CPE) (with a fractional power ‘alpha’) that is in parallel with a resistor. In this model the CPE expresses the capacitive behavior of the double layer at the electrode-tissue interface, and the resistor is used to express the faradic effect. Recently, a few studies suggested using two compartment CPE models for an inserted CI electrode into the cochlea.

In this study, we use single, dual, and triple component CPE models to find (i) how many CPE components are needed for a CI electrode-tissue interface model (without involving the tissue characteristics), (ii) what frequency range needed to have a robust model identification.

Methods: Oticon Medical CI electrodes were used in this study. For a given electrode inserted in saline water, single, dual, and triple CPE component models were fitted to the electrochemical impedance spectroscopy (EIS) data in the frequency range [0.1Hz - 1MHz].

Results: The single component CPE model exhibited an overall good fitting to the EIS data (Rf~=800 kΩ, CPE~=6.5 µF, alpha~=0.73). Small deviations from EIS data were observed in the impedance spectrum of the fitted model (both amplitude and phase) in very low frequencies around 10 Hz, and very high frequencies above 300 KHz.

Precise investigation of the EIS data revealed that two frequency-overlapped mechanisms are involved in the formation of EIS data at low frequencies. The slower mechanism impacts the EIS data up to ~50 Hz. It decreases the slope of EIS amplitude (and thus decreases the faradic resistance) and modifies the EIS phase so that the return to 0 degree occurs at a lower frequency. These findings were confirmed by dual component CPE model fitting. The estimation of the faradic resistor decreased from 800 kΩ to 500 kΩ, and the fractional power of the faster CPE component increased from 0.73 to 0.84.

This model fitting also showed that a precise faradic resistance estimation requires EIS data to be recorded for very low frequencies until a return to 0 degree is observed on the phase. Merely using the EIS amplitude cannot provide a good estimation for faradic resistor because the saturation of EIS amplitude is very difficult to be observed at low frequencies.
Finally, when the number of CPE components increased to three, a very fast CPE component was identified for frequencies above 300 kHz (CPE=0.3nF, alpha=1). This CPE component moves the EIS phase toward - pi/2 degree and reduces even further the EIS absolute value for very high frequency terms.

Conclusions: A single CPE component model is sufficient for EIS data fitting, however, if a precise value for the faradic resistor is required for a particular application, a dual component CPE model will be needed. If the number of CPE components increases to three, fast transient characteristics of the electrode-tissue interface to an incoming CI stimulation pulse can be expressed precisely.

1393: EFFECTS OF POLARITY, PULSE SHAPE, AND ELECTRODE CONFIGURATION ON CHANNEL INTERACTIONS

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Channel interactions and spread of excitation still remain a major issue with cochlear implants, particularly at high current levels. Despite extensive research on electrode configurations and the development of sophisticated current focusing techniques, their performance in patients often falls short of the expectations raised by animal- and modeling studies. Possible reasons include the high current required for focused stimulation offsetting the benefit and differential survival of auditory nerve in patients. We have previously demonstrated that the use of pseudomonophasic pulses and duration- instead of amplitude coding can reduce channel interactions for monopolar stimulation. Here, we present a comparison of mono- and tripolar, as well as a common ground, or distributed "allpolar" configuration, where the active electrode and the return electrode deliver a monopolar pulse, and all other array electrodes are grounded.

We implanted 20 anesthetized, acutely deafened guinea pigs with 6-channel cochlear implants (Oticon medical), and recorded multiunit activity from the inferior colliculus while delivering single pulses and low-frequency pulse trains through the apical cochlear implant differing in configuration (monopolar, tripolar, allpolar), waveform (biphasic, monophasic, pseudomonophasic), coding strategy (amplitude, duration), and leading polarity (cathodic, anodic). Pseudomonophasic pulses had a phase ratio of 1:5, and charge was kept constant between coding strategies by balancing duration and amplitude. We estimated the spread of excitation by analyzing the bandwidth of electrical tuning curves 1 dB above threshold, and the channel interactions by analyzing the vector strength to a target pulse train in the presence and absence of a distractor pulse train of different frequency on a different electrode at 6 dB above threshold for both stimuli.

While exhibiting similar rates and dynamic ranges to monopolar stimulation across conditions, allpolar stimulation required threshold currents between 3.3 and 8.5 dB higher than monopolar, with thresholds reducing from bi- through pseudomono- to monophasic pulses. Coding strategy played a minor role. Tripolar stimulation required between 10 and 12 dB higher currents than monopolar. Allpolar significantly improved the tuning width in virtually all conditions by up to 0.9 octaves compared to monopolar, whereas tripolar lead to tuning curves that were up to 2 octaves narrower than monopolar. Channel interactions were mainly influenced by pulse shape, with decreasing channel interactions (increasing vector strengths) from biphasic pulses to monophasic pulses. Interestingly, all pulse shape effects were considerably smaller for anodic stimulation than for cathodic stimulation. Duration coding consistently reduced the channel interactions compared to amplitude coding. Allpolar stimulation was superior to monopolar stimulation in all conditions but duration-coded monophasic pulses, with a maximum increase of 11.5 percentage points. In contrast, tripolar stimulation improved channel interactions by up to 55 percentage points. However, tripolar stimulation on average decreased the vector strength to pulse trains in the absence of distractors by 12 to 30 percentage points relative to monopolar, while allpolar did not, indicating that temporal coding in the midbrain might somewhat profit from a reduced spread of excitation.

This study demonstrates diverse effects of virtually all variable stimulus parameters on channel interactions, and suggests that allpolar configuration could represent a clinically viable compromise between monopolar and tripolar configuration.

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1408: DEVELOPMENT OF HIGHLY ACCURATE 3D PRINTED ARTIFICIAL COCHLEA MODELS

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Background. During cochlear implant (CI) insertion, the mechanical trauma causes a loss of residual hearing in up to 50% of implantations. This can severely limit CI performance through neural degeneration and fibrosis caused by acute mechanical damage and chronic inflammation. Present methods enabling detailed characterisation of the implant-cochlea interactions involve animal or cadaveric testing. However, animal and cadaveric samples come with limitations as they are difficult to source, instrument, and measure. Furthermore, they cannot be systematically varied in various shape or size parameters to examine the impact of these on insertion forces.

The aim of this project is to create highly accurate and optically clear 3D printed cochleae at a realistic scale within the range of shapes and sizes seen in humans and to measure insertion forces in them.

Methods. Human cadaveric temporal bones were imaged using micro-computerised tomography (microCT) scanner and reconstructed to produce computer-aided design (CAD) files. A variety of different 3D printing technologies were evaluated, such as multi-jet printing (MJP), digital light processing (DLP), continuous digital light processing (cDLP), and low force stereolithography (LFS) for the fabrication of an accurate artificial cochlea model. Based on the initial screening of these techniques, two 3D printers were chosen, and their performance was assessed in depth using scanning electron microscopy (SEM) and microCT. Post-processing of the models was optimised to achieve high optical transparency. Nominal-actual analysis was conducted to observe the deviation of artificial cochlea models and the original 3D reconstruction of microCT scans and compare multiple duplicates for statistical analysis. An insertion platform with a 1-axis load cell and a camera located above the model synchronised with the stepper motor to facilitate slow controllable insertion was developed for assessing factors such as insertion speed and insertion angle.

Results. DLP and LFS 3D printing technologies demonstrated superior performance with excellent surface smoothness and geometric accuracy. Furthermore, SEM analysis showed the variations between different printing settings of DLP technology (step-like finish) and a very smooth finish achieved by LFS technology. The nominal-actual analysis illustrated a significant difference between tested post-processing techniques. Furthermore, it indicated that 90% of the surface is within the deviation of 58 μm (six duplicates). Post-processing was optimised to achieve highly transparent models, which are necessary for studying the electrode array behaviour during insertion on the custom-designed insertion platform. This platform has enabled the evaluation of the effect of several factors on insertion force profiles such as insertion speed, round window geometry and approach. In preliminary experiments, higher insertion speeds increased the peak insertion force.

Conclusion. The production of highly accurate, optically clear models of the human cochlea using DLP and LFS 3D printing technologies is presented alongside the characterisation of insertion force according to different parameters. These models provide a good base for evaluating the insertion forces and behaviour of the implant during implantation.

1462: COMPLEMENTARY 3D PRINTED AND COMPUTATIONAL ELECTRICAL MODELS OF THE COCHLEA

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Background. The electrical current spread within the conductive cochlea severely limits the clinical effectiveness of cochlear implants (CIs). This significantly holds back the development of effective treatment strategies for this electrode-neural interface. Only limited measures are possible clinically and in cadavers to be able to characterise this spread and animal models do not replicate the human cochlear geometry.

Therefore, the development of electrical models of the cochlea are crucial to understand and optimise the electrical stimulation of the cochlea for optimal neural response and ultimately hearing outcomes. Using 3D printing techniques, coupled with insights from computational finite element models, it is possible to create and instrument models of the cochlea which can act as a platform to test both existing treatment strategies (e.g. processing strategies, multipolar stimulation) and to develop new strategies. Complementary methods are employed including a fully 3D printed model, simplified 2.5 dimensional cochlea on a chip models with neural cell integration and characterisation as well as a computational finite element model.

Method. Micro-computerised tomography (microCT) derived segmentation was used to generate 3D reconstructions of several human cochleae that could be 3D printed. However, in order to replicate the electrical properties of the cochlea, different models of the porous structures, filled with 1% saline, were implemented to replicate the porosity of temporal bone which largely determines the electrochemical conductivity of the cochlea. Furthermore, a cochlea on a chip model was fabricated from 3D printed mould to produce PDMS microfluidics to be placed on multielectrode arrays to characterise auditory neuron firing in response to the CI stimulation. These models allow the real-time characterisation of real CIs which include the non-linearities and electrochemical aspects of CI stimulation. Alongside this, a finite element model (FEM) was generated in COMSOL Multiphysics in order to sample 3D voltage, electric field and current fields within the model to replicate several clinically relevant scenarios.

Results. The production of accurate 3D printed models with a variety of porous structures has been successful, including channel-based porosity and gyroid based porosity. This is coupled by the incorporation of 16 hollow channels into the modiolus that allow the insertion of wires in order to sample the electric field. This has demonstrated close replication of clinical transimpedance measurements as initial validation of the model. Furthermore, cochlea on a chip models have demonstrated successful fabrication of a 3-channel structure interconnected by microchannels to allow neurite outgrowth of auditory neuron cells between the main channel compartments. Finally, the computational FEM models have been used to replicate and study several clinically relevant scenarios including the perimodiolar vs lateral wall positioning, extracochlear electrodes and tip foldover.

Conclusion. Through the combination of complementary methods, it is possible to formulate a well-rounded understanding of CI electrical stimulation on both a physical and cellular level. This couples the relevance of real time measurements of physical models with highly adaptive and detailed computational models which can sample several electrical parameters in 3D within the cochlear structure. Together, these models can be utilised to answer many clinically relevant questions to optimise the CI neural interface and improve patient outcomes.

1464: ULTRA-SHORT PULSE LASER BASED MANUFACTURABLE 32-CHANNEL COCHLEAR ELECTRODE ARRAY

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In this study, we introduce a manufacturable 32-channel cochlear electrode array. On the contrary to conventional cochlear electrode array manufactured by manual process which consists of electrode-wire welding, placement of each electrode, and silicone molding over wired structures, suggesting cochlear electrode array is manufactured by semi-automated laser-micro structuring and mass-productive layer-by-layer silicone deposition scheme similar to semiconductor fabrication process. Our 32-channel electrode array has 32 electrode contacts within a length of 24 mm with 0.75 mm spacing between each contact. And the width of electrode array is 0.35 mm at apex and 0.6 mm at base. To assess the feasibility as a commercially applicable solution, we conducted electrophysiological evaluation, stiffness measurement and insertion/extraction force measurement. The electrochemical impedance and charge storage capacity are measured as 3.11 ± 0.89 kOhm at 1 kHz and 5.09 mC/cm2, respectively. The vertical stiffness of the electrode array was 19.8 mN and the horizontal stiffness was 15.7 mN, with an average of 17.8 mN. The insertion force of the fabricated electrode array was 17.4 mN at 8 mm from the round window and the maximum extraction force was 61.4 mN. A novel 32-channel electrode array is developed using semi-automated fabrication process, which contrasts with the manual fabrication of conventional cochlear electrode arrays. We intend to provide cochlear implantation to more people who has hearing loss by further increasing the productivity of the cochlear implant through the innovation in method of producing cochlear electrode array.

1465: EXAMINING THE USE OF AN INVESTIGATIVE BALANCE PROSTHESIS DURING BALANCE TASKS IN CHILDREN AND YOUNG ADULTS WITH COCHLEOVESTIBULAR LOSS

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Objectives: To: 1) examine stability of children and young adults with cochleovestibular loss during simple balance tasks 2) examine postural responses of children and young adults with cochleovestibular loss to balance perturbations and 3) determine whether the use of an auditory balance prosthesis impacts balance task performance

Background: Children with profound deafness often experience concurrent balance deficits, as measured by a clinical balance assessment, the balance subsection of the Bruininks-Oseretsky Test of Motor Proficiency Second Edition (BOT-2). When baseline balance is poor, floor perturbations might disturb their posture to a greater extent than normal. Such balance deficits might be addressed by an investigative balance prosthesis, the BalanCI, that provides head-referencing cues through the user's cochlear implants. The present study tested the hypothesis that children and young adults with cochleovestibular loss display less stability during simple balance tasks and abnormal postural adjustments in response to balance perturbations than typically-developing peers, and that BalanCI use may improve performance on these tasks.

Methods: Fifteen typically-developing children (6 female) aged 7-18 years (mean age ± SD = 13.6 ± 2.75 years) and 8 children and young adults with cochleovestibular loss (6 female) aged 9-27 years (mean age ± SD = 19.5 ± 5.5 years) completed the BOT-2. Participants also completed a perturbation task; they stood on a treadmill and were asked to remain upright despite experiencing forward, backward, left and right (direction) perturbations that could be small, medium or large (magnitude). Both tasks were completed with the BalanCI on and off. Kinematic measures were captured using motion capture markers worn on the head, upper body, pelvis and feet. Typically-developing children were presented with cues from the BalanCI bilaterally through insert earphones.

Results: Preliminary analyses of perturbations suggest that participants with cochleovestibular loss adopt different patterns of movement responses to perturbations, with less return to initial position post-perturbation compared to typically-developing children (95% CI range, $p < 0.01$). Participants with cochleovestibular loss demonstrated significantly lower age-scaled BOT-2 scores than typically-developing children (95% CI, $p < 0.01$), but thus far, no main effect of BalanCI on score in either group is evident (95% CI, p's > 0.1). Motion capture data for both tasks are undergoing analysis.

Conclusions : Findings suggest that children with cochleovestibular loss may respond to perturbations of the floor differently than typically developing peers. Future analyses will examine other aspects of perturbation response, as well as postural stability during the BOT-2, and whether BalanCI use impacts responses during these tasks.

1473: CHARACTERIZATION OF DISTRIBUTED ALL-POLAR STIMULATION MODE, A POWER-SAVING PARTIAL MULTIPOLAR MODE

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Cochlear implants (CIs) restore hearing sensations for those whose hearing loss precludes them from obtaining sufficient benefit from conventional amplification. Although it provides good outcomes in quiet conditions, complex and noisy listening situations are still challenging for CI recipients. One explanation for this includes the sub-optimal electrode-neuron interface that today's CIs provide. Generally, the most usual CI stimulation paradigm uses biphasic symmetric pulses in monopolar mode, where amplitude modulation is employed to encode loudness. While such stimulation paradigm is known for achieving high stimulation efficiency, the spread of current is major and results in decreased outcomes especially in complex listening environments.

Since multipolar and partial-multipolar stimulation modes were described in past literature, with documented benefits on the reduction of spread of excitation, none of them are used in clinical devices because of their high-power consumption.

Oticon Medical CIs use in their clinical configuration a different stimulation paradigm that allows partial multipolar stimulation with limited power consumption. Firstly, the stimulation mode, called Distributed All-Polar (DAP), uses all non-stimulating available intracochlear electrodes and an extracochlear reference electrode as return paths to provide a focused electrical stimulation. Secondly, the pulse waveform includes an active anodic stimulating first phase, and a non-stimulating cathodic phase. During this second phase, the stimulating electrode with its serial capacitor is connected to the ground to allow charge balancing thanks to capacitive discharge following an exponential decreasing shape. This pulse waveform then requires only half of the current needed for generating a biphasic square pulse. Last, pulse width modulation is used for loudness coding, with a fixed amplitude on all stimulating electrodes. Such coding prevents device out-of-compliance issue that can happen at higher amplitudes and are influenced by electrode impedance.

This poster presents an electrical characterization of the DAP mode combined with specific stimulation shape modulated in duration and amplitude from ex-vivo measurements. Particularly, all current flows from stimulating electrodes to intra- and extracochlear return electrodes were measured: the ratio between extracochlear and intracochlear current flow was measured to be about 25%. The possible benefits offered from this stimulation paradigm will also be discussed.

1483: AN INSTRUMENTED COCHLEA MODEL FOR THE EVALUATION OF COCHLEAR IMPLANT ELECTRICAL STIMULUS SPREAD

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Cochlear implants use electrical stimulation of the auditory nerve to restore the sensation of hearing to deaf people. Unfortunately, the stimulation current spreads extensively within the cochlea, resulting in “blurring” of the signal, and hearing that is far from normal. Current spread can be indirectly measured using the implant electrodes for both stimulating and sensing, a configuration that provides imprecise information due to electrode-electrolyte interface effects when current is delivered. Here we present a 3D-printed “unwrapped” physical cochlea model with integrated sensing wires. We integrate resistors through the walls of the model to simulate current spreading through the cochlear bony wall, and tune these resistances by calibration with an in-vivo electrical measurement from a cochlear implant patient. We use this model to compare the current spread under different stimulation modes including monopolar, bipolar and tripolar. A trade-off is observed between stimulation amplitude and focusing among different stimulation modes, matching previous literature and confirming the validity of this artificial cochlea. By combining different stimulation modes and changing intracochlear current sinking configurations, we explore this trade-off to search for optimal stimulation amplitude and focusing. These results will inform clinical strategies to use in delivering speech signals to cochlear implant patients. In future work, we aim to build a refined artificial cochlea for further research providing even more densely-packed data on spread within the cochlea and reduction methods for improving patients' quality of life.

The work can be found at:
C. Jiang et al., "An Instrumented Cochlea Model for the Evaluation of Cochlear Implant Electrical Stimulus Spread," in IEEE Transactions on Biomedical Engineering, doi: 10.1109/TBME.2021.3059302.

1491: A BINAURAL CI RESEARCH PLATFORM FOR ALL OTICON MEDICAL IMPLANTS – AN UPDATE

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First released for Digisonic-SP implants in January 2021, the Oticon Medical Research Platform (OMRP) is a safe, binaural, real-time research platform for Oticon Medical cochlear implants. Now, a new release targeting the newer Neuro-Zti implant is due in December—timed to coincide with the release of the Neuro-Zti to the US market. The platform is a PC-based [1] benchtop sound processor capable of synchronously digitizing signals from 4 ear-worn microphones simultaneously and processing the audio inputs to produce two synchronized outputs to drive two (bilateral) implants. The platform can control electrode timing to better than 2 microseconds. The Neuro-Zti release will allow new comparative studies in humans including: (1) monopolar, bipolar, and common ground modes, (2) passive vs. active charge recovery, (3) different timings of charge recovery. Here we detail the types of stimulation that can be achieved and invite interested researchers to see demos of the system. A series of training videos describing how to use and program the system will be made available. The OMRP is also designed to integrate into a growing ecosystem of Oticon Medical research tools including a VR system for sound localization studies, pupillometry measurements for listening effort studies, and an experiment design tool to help researchers more quickly create psychophysics experiments. A full API that enables real-time binaural control will be made available to researchers working with the platform.

1493: CCI-MOBILE: BILATERAL AND BIMODAL SYNCHRONIZATION WITH THE CI/HA RESEARCH PLATFORM

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While speech understanding for cochlear implant (CI) users in quiet is relatively effective, listeners experience difficulty in identification of speaker and sound location. Previous studies have reported improved localization and better speech perception when the CI is coupled with a second CI or hearing aid in the contralateral ear. This is referred to as bilateral or bimodal presentation of speech [1,2].. A major obstruction to accurate source localization for bimodal and bilateral CI users is the distortion of interaural time and level difference cues (ITD and ILD), and limited ITD sensitivity [3]. Hence, it is necessary to develop and test algorithms that provide better localization and sound source identification cues. Various CI research interfaces developed by either academic or industry sponsored research teams support proposed signal processing and psychoacoustic investigations but have limited ability to efficiently validate bimodal and/or bilateral algorithms. Platforms that support bimodal testing are either not portable or only provide limited features due to proprietary parameters/routines. Thus, the open-source, portable signal processing platform, CCi-MOBILE developed by UT-Dallas, enables electric and acoustic bilateral stimulations simultaneously, providing researchers the freedom to explore new technology and scientific paradigms. In the present work, we will provide verification of synchronized bilateral (electric-electric) and bimodal (electric-acoustic) output in an authenticated and efficient manner to support localization algorithmic and experimental investigations.

The verification test paradigm analyzes left and right RF channels captured using CCi-MOBILE via CI24RE implant emulators which mimic the functionality of the intracochlear electrode array. CCi-MOBILE captures audio in real-time through two behind the ear (BTE) microphones via an audio codec and streams the digitally processed signal through a UART port to the computing platform (PC/ smartphone). Sound processing routines send the RF data through the UART port to RF coil to deliver biphasic pulses in a continuous interleaved manner (CIS). Results are verified using an oscilloscope to demonstrate the left and right output signals superimposed on each other, proving evidence of simultaneous CI/CI and CI/HA synchronization. Similarly, bimodal stimuli synchronization will be verified by comparing the Electric and Acoustic Stimulation (EAS) outputs on an oscilloscope to demonstrate equalization of the input and output time delay for both channels.

This work was supported by the grant R01 DC016839-02 from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health.

1500: WHILE SYNCHRONIZING AGCS CAN AMELIORATE SOUND-SOURCE LOCALIZATION DIFFICULTIES INTRODUCED BY INDEPENDENT AGCS, INDIVIDUAL EFFECTIVENESS IS LIMITED BY LISTENERS' BASELINE PERFORMANCE WITHOUT AGCS ENGAGEMENT

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For cochlear implant (CI) patients, automatic gain control (AGC) is used to compress the roughly 120-dB range of human hearing into the 3–20 dB range of useful electrical stimulation. Typically, AGCs are independent in left and right CIs, and this can lead to distortion of interaural level differences (ILDs) which are the primary spatial cue available to bilaterally-implanted CI patients. Synchronizing AGCs would ideally create ILDs that are more closely correlated with the actual ILDs at the listeners' ear drums -- both when listeners are stationary and when they move their heads.

In a first experiment, we compared localization acuity for 7 listeners in the frontal hemifield with independent vs. synchronized AGCs, both with and without head movements, for long-duration noise stimuli presented at 70 dBA. In a second experiment we evaluated the same listeners' ability to use the changes in ILD that occur with head movements to determine the front-back location of the same sound stimuli presented from 360º around the listeners, again with independent vs. synchronized AGCs, both with and without head movements, and this time at 70 dBA and a 50-dBA baseline condition where AGCs were not engaged.

Results showed that nearly all listeners' horizontal sound source localization acuity improved in both experiments, but to widely differing degrees. Head movements made little impact in both experiments, and listeners were in general not able to use head movements to reduce their rate of front-back reversals, with or without AGC compression, regardless of whether AGCs were synchronized or not, or for that matter, engaged at all. Synchronization of AGCs did, however, facilitate the use of pinna-related spectral cues introduced by the use of an in-ear microphone for two listeners. Synchronizing AGCs generally returned listeners' performance to approximately what it was when stimuli were presented at 50 dBA in the baseline condition where AGCs were not engaged.

Signal Processing – Invited and Featured Talks + Posters

Invited Recorded Talk

1521: INVESTIGATING CAUSAL MECHANISMS OF SPEECH PERCEPTION WITH COCHLEAR IMPLANTS: FINDINGS WITH SPECTRAL BLURRING

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Most cochlear implant (CI) listeners experience difficulties in perceiving speech in situations with interfering sounds. This is partly due to current spread between the stimulating electrode channels, leading to wide neural excitation patterns and detrimental channel interactions. Reducing channel interactions may therefore lead to improved speech perception with CIs. However, this has not yet been achieved and mixed results have been reported for strategies that manipulated the electrical stimulation patterns. We conducted a series of experiments to investigate the causal effects of channel interaction by using spectral “blurring” as a simulation of increased spread of excitation. We measured effects on speech intelligibility: (1) for different types and degrees of blurring, (2) when applied to all or subsets of channels, (3) using equally spaced or clustered channels along the electrode array and (4) to determine blurring thresholds for individual listeners.

As expected, we found that increased channel interaction due to spectral blurring degraded speech perception with CIs. However, this was only the case when all electrode channels were affected and surprisingly not when only a subset of spaced channels was affected. Further, we found that even when deactivating the subset of blurred channels, there was no apparent degradation in performance. When all electrode channels were blurred by increasing amounts, speech perception thresholds worsened only beyond some value. That value differed between listeners and correlated with their performance on a spectro-temporal test and speech performance with the clinical-like map. There were differential effects for blurring at different segments of the electrode array, with a significantly stronger degradation of speech intelligibility when the most apical cluster of electrodes was blurred. Finally, blurring effects were consistent for two different types of background noise and even for speech in quiet with a different speech corpus.

Spectral blurring revealed some surprising findings, such that even large amounts of blurring do not seem to harm CI speech perception when equally spaced electrodes are affected, or when these are clustered at the more basal end of the array. These findings should inform electrode-deactivation strategies that build on surrogates of spread of excitation. Individual blurring thresholds revealed differences between listeners that were associated with their listening performance and could be used to identify listeners that may benefit most from strategies that aim to reduce channel interactions. We propose that causal manipulations such as spectral blurring could be used as a means to assess new stimulation strategies for CIs, for example those that aim to improve performance via more sparse stimulation patterns. This would avoid confounding differences between listeners and interactions within listeners in terms of spectro-temporal, linguistic and cognitive abilities.

Featured Recorded Talk:

1510: THE COCHLEAR IMPLANT HACKATHON: CROWDSOURCED ALGORITHM GENERATION FOR IMPROVED AUDITORY PERFORMANCE

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Although there have been substantial improvements in cochlear implant (CI) signal processing strategies over the past 30 years, the auditory performance of modern CI users does not approach that of normal-hearing listeners on most objective metrics. Novel strategies of signal processing may substantially improve the experience of CI users. We generated a web-enabled competition (cihackathon.com) in order to crowdsource the generation of novel signal processing strategies for improved CI auditory performance. Entrants into the competition were provided with annotated source code as a starting point to simulate a state-of-the-art baseline CI signal processing strategy, as well as instruction on how common CI signal processing strategies function. Entrants were also provided with audio clips and an electrodogram-based vocoder to simulate the auditory percepts generated by any given signal processing strategy. After generating novel strategies, entrants were provided with sample audio files and would submit the code for their strategy as well as matrix files containing electrode activation information for each clip. Entries were judged for four types of audio inputs: Consonant-nucleus-consonant (CNC) words, sentences, sentences in noise, and music. 69 teams registered for the hackathon, and 17 teams submitted complete entries. Entrants were from 5 continents and a diversity of personal and professional backgrounds. 12 of the 17 entered strategies performed better than the provided baseline strategy for at least one of the four tasks, with 7 teams performing better than the baseline overall. Among the best-performing strategies were a diversity of approaches, with no two submitted strategies being meaningfully identical. Multiple teams are planning on carrying forward their strategies for further development. We conclude that crowdsourced idea generation, even for a task as complex as developing CI signal processing strategies, is feasible, may yield critical novel ideas, and can bring talented researchers into the field who otherwise would not have had the opportunity to participate.

1339: THE EFFECT OF COCHLEAR-IMPLANT DYNAMIC-RANGE COMPRESSION ON THE PERCEPTION OF MOVING SOURCES IN NORMAL-HEARING LISTENERS

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Dynamic-range compression (DRC, sometimes referred to as automatic-gain control) is used in cochlear-implant (CI) processing to maintain the audibility of sounds for CI users. DRC parameters in CIs are often much stronger than those found in hearing aids. As such, DRC can have a much greater effect on the level and envelope of sounds. Previous work (Archer-Boyd and Carlyon, 2019) that simulated the effect of unlinked Advanced Bionics DRC on interaural level differences (ILDs) showed that, during head movements, revealed that the DRC can introduce across-frequency inconsistencies in the direction of ILDs and that some parameters lead to “overshoot”, whereby ILDs continue to change after head movements have ceased. This study investigated the effect of different DRC parameters on the perceived trajectories of moving sounds by normal-hearing (NH) listeners listening to noise-vocoded CI simulations.

Moving sound sources were produced using the overlap-add method detailed in Archer-Boyd and Carlyon (2019), using head-related impulse responses (HRIR) from the anechoic Oldenburg behind-the-ear microphone HRIR library. High-pass pre-emphasis, and single-channel, unlinked DRC was applied to the moving signals. Several combinations of compression ratio, attack, and release time were investigated. 16 analysis filters from 0.25-8kHz were used in the noise vocoder. The synthesis filters were shifted by three octaves in order to reduce the effect of uncontrolled interaural-time-difference fluctuations on responses. Four groups of three channels, and three groups of six channels from synthesis channels 3-14 were presented, from low to high frequencies. An additional broadband condition using 12 channels (3-14) was also presented. Listeners were screened for very high frequency hearing loss (10.7 kHz). Listeners drew the perceived trajectory of the sound on a top-down schematic of a head directly after stimulus presentation.

Results were mixed across listeners, partially as a result of allowing them to freely draw the perceived movement. The compression caused the lowest frequency band to be perceived as moving in the opposite direction to the input sound, or as a static sound, consistent with simulations described by Archer-Boyd and Carlyon (2019). In general, for higher frequency sounds, increases in compression ratio and decreases in attack and release times resulted in reduced perceived movement. A subset of listeners perceived the “overshoot” effect described in Archer-Boyd and Carlyon (2019), where the sound reversed direction of movement towards the end of the stimulus. As the bandwidth of the presented sounds was increased, results became more variable across listeners. Some reported hearing no clear position for the sound, before, during, or after movement, and there was an increase in the perception of two sound sources. Results across spectral regions and variable bandwidths were compared, in order to investigate how listeners combined dynamic ILD cues across frequency for different compression parameters.

This study confirmed that DRCs can distort the perceived location of moving sounds in a manner consistent with the model of Archer-Boyd and Carlyon (2019), and provided evidence on the way listeners combine conflicting across-frequency cues when judging sound movement.

1352: PHONEME-BASED TIME-FREQUENCY MASK ESTIMATION FOR REVERBERANT SPEECH ENHANCEMENT FOR COCHLEAR IMPLANT USERS

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Cochlear implant (CI) users experience substantially more difficulty in understanding speech in reverberant listening environments as compared to their normal hearing counterparts (Kokkinakis et al., 2011). A common speech enhancement technique is time-frequency (T-F) masking, where a matrix of gain values is applied to the T-F representation of reverberant speech to suppress reverberant reflections. Because the mask is unknown in real-time, an algorithm is required to estimate the mask using features extracted from the reverberant signal. Current algorithms typically estimate the T-F mask by applying machine learning models to a set of time-frequency features. The spectro-temporal structure of speech is highly variable and dependent on the acoustic environment, which can limit the ability of a mask estimation algorithm to generalize to unseen acoustic environments (Chazan et al., 2017).

One way to potentially overcome this variability is to incorporate knowledge of the phonemic structure of speech to better distinguish target speech from reverberant reflections. Phonemes are generally concentrated in specific frequency ranges, with vowels containing primarily low frequency content and fricatives containing high frequencies. Thus, we hypothesize that a phoneme-based algorithm can provide a more accurate estimate of the T-F mask. Furthermore, phoneme-based speech enhancement algorithms have improved the performance of automatic speech recognition models in reverberant environments (Wang et al., 2016), so we hypothesize that a phoneme-based approach to T-F masking may potentially benefit CI users.

We propose a phoneme-based T-F mask estimation algorithm, where a separate mask estimation model is trained for each phoneme. Using a remote testing framework, we conducted sentence recognition tests in normal hearing listeners to determine whether phoneme-based masks improve the intelligibility of vocoded speech in the ideal case where the phoneme is known exactly. The algorithms were tested in three reverberant environments: an office, a stairway, and a church. The results demonstrated higher phoneme recognition scores for speech enhanced using phoneme-based masks (office: 67.8±17.4%, stairway: 76.8±14.3%, church: 38.8±18.4%) than for speech enhanced using phoneme-independent masks (office: 53.3±18.4%, stairway: 55.2±19.6%, church: 25.9±17.1%). Future work will test the phoneme-based T-F mask estimation algorithm in the non-ideal case where the phoneme-specific mask estimation model is selected based on the prediction from a phoneme classification model.

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1378: ELECTRICALLY EVOKED AUDITORY STEADY-STATE RESPONSE AND STIMULATION ARTIFACT ESTIMATION USING KALMAN FILTERING

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Cochlear Implants (CIs) can be used to restore hearing of people with severe to profound hearing loss. Part of the hearing restoration process is the regular CI fitting, which is time consuming and with a large variability across clinicians and CI recipients. Furthermore, it requires interaction with the subject and is therefore difficult to assess in populations that cannot give reliable subjective feedback, such as infants. Electrically evoked auditory steady-state responses (EASSRs) can serve as an objective measure to determine stimulation levels, and are therefore a promising step towards fully automated, objective fitting of CIs. A major challenge when recording EASSRs are the stimulation artifacts of the implant, which make the neural response detection in EEG cumbersome. Methods such as Linear Interpolation (LI), Template Subtraction (TS) and Independent Component Analysis (ICA) have been used to remove the artifact from the measured signal. However, they either fail to clearly separate artifact and response (ICA), require extra measurements (TS) or are unable to remove the artifact when it exceeds the inter-pulse interval (LI), e.g. for clinical stimulation settings of the CI. Here, Kalman Filtering (KF) is used to estimate EASSRs on a dataset of 10 adult CI users as acquired in [Gransier et al (2020) Sci. Rep. 10:15406]. EASSRs were elicited with commonly used CI settings (900pps, monopolar mode), over a range of modulation frequencies from 34Hz to 43Hz. Instead of requiring a-priori knowledge of the expected artifact shape to estimate the neural response, the KF approach estimates both, the neural response and the required artifact model.

Preliminary results show that KF is able to differentiate neural response and stimulation artifact, even without removal of signal components as for instance required in LI. The latencies of the responses are similar to those reported in the literature, indicating a good separation between artifact and neural response. Furthermore, KF is in some cases able to remove the artifact when LI fails to do so.

In conclusion, our KF approach is able to estimate a linear model of neural response and stimulation artifact when using clinical stimulation parameters. The advantages of KF over other artifact removal techniques will be discussed at the conference.

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1398: SYNTHETIC FEATURE EXTRACTION (SFX): AN ALGORITHM FOR EFFICIENT ESTIMATION OF SPECTRO-TEMPORAL INFORMATION FOR CI CODING

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CI users can often achieve high degrees of speech understanding (non-tonal languages) in quiet conditions but frequently report difficulties in complex listening environments, challenges understanding tonal languages, and disappointment when listening to music. These issues can be, at least partly, explained by limitations in pitch coding. Conventional CI coding strategies typically encode temporal envelopes and coarsely convey pitch through fundamental frequency (F0) cues contained in those envelopes and through place-of-stimulation. More advanced strategies could opt to (for example), enhance F0 cues, as well as, introduce information from harmonics that are also important for pitch perception in unimpaired listeners. This would require algorithms that can accurately identify and extract F0 and harmonic cues. To be implementable in a clinical CI sound processor, such an algorithm must real-time compatible (e.g., low processing delay), robust to noise, and comprise minimal computational complexity.

The ‘Synthetic Feature eXtraction’ (SFX) algorithm has been designed to extract temporal and spectral parameters in real-time from key spectral features (e.g., F0, harmonics, formants, etc) in acoustic signals. The key spectral features are identified as the local maxima in a sliding Fast Fourier Transform (FFT). By exploiting knowledge about the way in which the FFT inherently smears spectro-temeporal information, the algorithm then attempts to estimate parameters of those features with a higher degree of accuracy than that offered by the FFT directly.

Evaluation of SFX indicates negligible errors when estimating the frequency, energy and phase of pure tones both in isolation and as part of tone-complexes. SFX is also able to estimate F0 and harmonic frequencies in simple melodies and in voiced/tonal speech with errors of just a few Hz. These errors are substantially lower than errors when estimating from the FFT directly, or when using time-domain filter-band methods. Furthermore, when the output of SFX for those signals is resynthesized, subjective sound quality tests thus far indicate high fidelity relative to the original unprocessed acoustic signal.

1399: SIGNAL PROCESSING FOR COCHLEAR IMPLANTS: COMPARISONS OF RELATIVE DISTORTIONS TO SPEECH SIGNALS.

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Modern multichannel cochlear implant (CI) systems require simple signal processing to decompose environmental sound signals into frequency bands where most energetic will convey information to auditory nerve fibres via intracochlear electrodes. Hardware design only allows for few numbers of physical electrode contacts and most chips do not allow to lock the stimulation at variable and specific timings. However, next generation of CIs may benefit from the evolution of new nano circuitry technologies that will unlock flexible pulse generation with minimum power consumption, while micro and nanomanufacturing will enable electrode arrays embedding higher density with smaller electrode contacts. Most signal detection processing will be outdated (e.g. Fast Fourrier Transform or IIR/FIR Filterbanks), providing either low calculation computation power but moderate frequency resolution (FFT) or finer resolution with the cost of extremely demanding in calculation power (IIR/FIR). The Spectral Feature eXtraction (SFX) is able to overcome most of the signal processing limitations existing in Filterbanks, providing accurate frequency estimation on over 60 channels with low calculation power. The SFX combines the signal information from double Short Time Fourrier Transform (SFTF) to recreate the signal energetic components the closest possible to the original signal with no channel limitation.

This study evaluates the capability of SFX to preserve sound features at the basic information transfer level, i.e. after proceeding to nofm and just before the CI encodes information into pulses. The resulting processed signals from an SFX, FFT and IIR Filterbank (FB) method were then reconstructed and analysed with tools already described in the literature, with the final aim of comparing their relative distortion with respect to the original sounds. During the analysis, the signals were first fed to a feature analyser (MIR), a dimension reduction method was applied to extract the principal robust components constituting them, and to find the most prominent feature dimensions between the original and processed signals. They were then passed to a parametric statistical model to investigate how processing strategies affect those acoustic features and whether there was a significant and systematic difference among processing methods. Then, same signals were passed through a speech prediction algorithm (ESTOI) known for its spectro-temporal analysis capabilities. The relative ESTOI metrics taken from the comparison between an original and processed signal were again compared between processing methods.

1419: FOR WHICH PATIENTS DO BINAURAL BEAMFORMERS GIVE ADDITIONAL SPEECH INTELLIGIBILITY BENEFIT BEYOND THAT OF TWO MONAURAL BEAMFORMERS?

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Binaural beamforming technology in hearing devices allows for all microphone signals (for instance two on a cochlear implant (CI) and two on a contralateral hearing aid, HA) to be processed together to provide much more focused spatial filtering than with two independently working monaural beamformers. However, focused spatial filtering that improves the signal-to-noise ratio distorts binaural aspects of hearing, such as interaural level and time differences, which may in turn counteract possible benefits in speech intelligibility. The goal of this study is to collect evidence for which patients using hearing prostheses do binaural beamformers give additional speech intelligibility benefit beyond that of two independent monaural beamformers and for which not. Answering this question from studies with beamforming algorithms from the different manufacturers is difficult, because of differences in (company-secret-kept) directional microphone technology, differences in acoustic scenes and because comparisons across different patient groups contrasting binaural and monaural beamformers are rarely done.

This study compares SRTs from three published studies [Baumgärtel et al., 2015; Völker et al., 2015; Zedan et al., 2021], in addition to unpublished data, all using the same open-source beamforming algorithms on the open Master Hearing Aid (MHA) platform and using the same realistic cafeteria acoustic scene across studies. The studies cover bimodal and bilateral CI users, bilateral HA users, as well as normal-hearing (NH) listeners.

The results show that bimodal CI users obtain significantly lower (better) speech reception thresholds (SRTs) with bilateral beamformers than with monaural beamformers (median additional SRT improvement: 4 dB), which is also the case for bilateral CI users (3.4 dB additional improvement). Bilateral HA users and NH listeners do not show the same effect (SRT improvement 0.1 dB). However, NH listeners do get an additional speech-intelligibility benefit if they only have one ear available, i.e., if one ear is not presented with acoustic signals (mean SRT improvement: 2.1 dB). The comparison of different patient groups here supports the hypothesis that only those bilateral hearing device users can receive significant additional benefit from binaural beamformers beyond that provided by monaural beamformers, whose physiological binaural fine-structure processing is dysfunctional (Baumgärtel et al., 2015).

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1422: THE SILENT STREAM: REMOVAL OF BACKGROUND MUSIC IN COMMUNICATION SETTINGS USING AUDIO STREAMING AND AN ADAPTIVE FILTER

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A complaint among cochlear-implant listeners and users of other hearing devices is the level of background music in public and commercial spaces. Many of these spaces now use streaming services and wireless loudspeaker systems to play music. The Silent Stream simulates a novel combination of these services and systems with future hearing devices. Music being streamed and transmitted to loudspeakers in a space can also be sent to the hearing device. This clean music signal can then be filtered out of the microphone signal from the hearing device using an acoustic echo-cancellation method.

Dynamic spatial audio simulations of several different restaurant configurations were produced using the 3D Tune-In toolkit software (Cuevas-Rodriguez et al., 2019), male and female talkers from the IEEE (York) and BKB sentence corpuses, and a variety of background music styles. A constrained frequency-domain adaptive filter (FDAF) was used to filter out the background music. We analysed the main effects of, and interactions between, the following effects: music type, transmission delay, talker-to-music level ratio, talker-to-background talker level ratio, reverberation, and listener movement. Estimates of speech intelligibility and the perceived quality of the signal after filtering were obtained using the short-time objective intelligibility (STOI) and the perceptual evaluation of speech (PESQ) measures, respectively.

A designed experiment (DoE) analysis showed an average improvement in STOI of 0.1 (equivalent to approximately a 5 dB signal-to-noise ratio improvement) across all conditions, ranging from no improvement in highly reverberant simulations with head movement and transmission delay, to 0.31 in no reverberation simulations with a static head position and no transmission delay. The improvement in STOI also varied across music types. The PESQ results showed similar trends.

A vocoder speech-in-noise task using a subset of conditions used in the DoE analysis was presented to normal-hearing listeners, in order to investigate the potential performance of cochlear-implant (CI) listeners using Silent Stream. The results of this listening experiment will be presented and compared to the DoE results.

The Silent Stream is a realistic simulation of a novel use of wireless audio streaming technology that could be implemented in real applications with current technology. Simulations have been used to investigate how the algorithm would perform in different acoustic environments, and produced predicted improvements in both the intelligibility and perceptual quality of speech, indicating benefits for its application in hearing devices.

1435: DESIGN AND EVALUATION OF A BINAURAL SOUND CODING STRATEGY BASED ON SYNCHRONIZED LINKED BAND SELECTION AND FRONT-END PROCESSING

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Introduction: Bilateral cochlear implant (BiCI) users have difficulties understanding speech and localizing sounds when compared to normal hearing (NH) listeners. This is mainly due to distortions of binaural cues such as interaural level and time differences (ILDs and ITDs), on which NH listeners rely to perform these tasks.

BiCI users make use of two independent CIs. These stimulate the auditory nerve on each listening side in an asynchronous way and process the incoming acoustic signals independently, greatly degrading binaural information. This degradation is caused, among other reasons, by the limited available electric dynamic range, and by frequency distribution differences across ears. In N-of-M type sound coding strategies, where the N most energetic frequency bands are selected for stimulation, these frequency distribution differences arise when different bands are selected in each of the devices leading to interaural spectral decorrelation.

Motivated by the limitations in binaural hearing that BiCIs have, we present a concept binaural sound coding strategy that uses bilaterally synchronized linked band selection and front-end processing algorithms that aim at both, improve speech understanding and sound localization in BiCI users.

Methods: Binaural unmasking and left/right discrimination accuracy were tested in 10 Nucleus (Cochlear Ltd., Sydney, Australia) BiCI users. Binaural unmasking was tested based on the HSM sentence set, with the speech coming from the front and CCITT noise located in the best-performing ear, and was tested to assess the effect of bilaterally synchronizing both CIs and linked band selection on speech intelligibility. For the left/right discrimination test, discrimination was tested using a two-interval, two-alternative forced-choice paradigm using broadband noise bursts, and was tested to investigate the effect of linked band selection and the effect of an ILD enhancement method, on left/right discrimination accuracy. The ILD enhancement method was designed to emphasize ILDs based on the direction of arrival of the target signal. For the front-end processing algorithms, an azimuth estimator (necessary for the ILD enhancement method) and a binaural speech enhancement method, both based on deep neural networks, were objectively tested to assess their potential effects when combined with linked band selection and the ILD enhancement method.

Results: Synchronized linked band selection had a small, but significant effect on speech intelligibility scores and the ILD enhancement method improved left/right discrimination for small azimuths and linked band selection improved it at larger azimuths, but only in 3 out of 10 BiCI subjects, specifically, in the ones that showed the poorest performance using unlinked band selection. Objective results indicate that the azimuth estimator can reach 96% accuracy in the horizontal plane, and the speech enhancement method shows that sharing information between the left and right CIs, is relevant to obtain better performance.

Conclusions: Behavioral and objective measures indicate that a binaural sound coding strategy that uses synchronized speech processors, linked band selection, and front-end processing methods may be desirable in the tested listening scenarios.

1444: USING THE ZERO-CROSSING PATTERN OF THE SPEECH WAVEFORM TO MAP SPEECH-FREQUENCY BANDS TO COCHLEAR-ELECTRODE PLACEMENT

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In contemporary cochlear-implant Speech Coding Strategies (SCS) the coding relies on mapping spectral speech bands to the spatial placement of the electrodes: as the spectral-band frequency increases the electrode distance from the base decreases. The zero-crossing speech strategy (ZCP) proposed here relies on the well-known fact that, for sinusoidal sounds there is an inverse relation between the sound frequency and the duration of the time interval between two adjacent zero crossings (IAZC). The ZCP capitalizes on the zero crossing properties of the time speech waveform: to a degree, the IAZC conveys information about the instantaneous spectral information of the speech waveform, with longer IAZC corresponding to lower frequencies and shorter IAZC to high frequencies. In the ZCP coding strategy, the full range of possible IAZC is quantized to 16 possible IAZC discrete bins, each of which activates one of 16 intra-cochlear electrodes: the shortest IAZC activate electrodes near the base and longest IAZC activate electrodes near the apex. Vocoder simulation with 16 and 8 electrode arrays showed 8 to 12% better speech recognition with the ZCP than the SCS strategy, and the ZCP speech is judged more natural. Testing the ZCP strategy versus FS4 on two MED-EL cochlear-implant users with 12 electrodes showed improvement on the VCV, envelope, frication, voicing, and speech reception threshold tests. However, with monosyllabic words the ZCP is 5 to 7% lower than the FS4. The main problem with the ZCP strategy is the impact of noise on generating repetitive zero-crossings. A solution under study to this problem is filtering out high frequency components in a noisy speech and using the positive and negative peaks in the speech signal to determine the segments durations instead of using the zero-crossing.

1446: THE EFFECTS OF QUALITY, LOUDNESS, AND INTELLIGIBILITY USING A LOMBARD PERTURBATION ROUTINE FOR NORMAL HEARING AND COCHLEAR IMPLANT LISTENERS

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The Lombard Effect (LE) can be described as the acoustic speech production changes due to the speaker's exposure in the surrounding environment. It has been previously shown that listening to Lombard speech for speech-in-noise tasks increases the intelligibility for NH listeners. More recently, our group also demonstrated that CI users also display LE and there are intelligibility benefits for CI listeners (Hansen et al., 2020). In this study, two variations of Lombard perturbation routines were developed to determine the effect on sentence intelligibility for both NH and CI listeners. Two variations: LOM-5 and LOM-4 named according to the number of modified features, manipulated: spectral contour, duration, pitch, and intensity, and fundamental frequencies (LOM-5 only), in an offline manner without durational constraints. An experimental protocol was developed to present LE perturbed speech at two levels of large-crowd-noise, +10 and +5 dB SNR. The experiment was conducted in an online, virtual environment where listeners were provided acoustic stimuli binaurally via headphones after volume calibration and training. Two alternate controls were used to determine the effect of loudness/presentation level: (1) the control presented at 65 dB SPL, and (2) the control root-mean-square normalized to the perturbed signal. Five groups of NH users were tested which varied according to perturbation routine, the control, and speech database employed. The AzBio sentence database was used to evaluate four groups and a single group was evaluated using the IEEE database. A total of 28 NH and 2 CI listeners participated in this study. Results from the NH groups indicate no average intelligibility improvement in either perturbation variation for the AzBio dataset. However, results from the frequency-warped perturbation routine (LOM-4) indicated an increasing trend of intelligibility as shown by one of the five NH groups. Overall, better performance was observed when both strategies were controlled for loudness, (i.e., the RMS-normalized controls). Larger deviations in Itakura-Saito objective measures were observed with the non-frequency warped variation (LOM-4), whereas PESQ scores were similar between both routines. The distortion was found to play a more important role in speech intelligibility for NH listeners than speech quality. Results from the CI group indicate increasing performance with decreasing SNR with average improvements of +9.4% points at +5 dB SNR using the non-frequency warped routine (LOM-4). Implications on future iterations of LE perturbation routines and integration of LE pre-processing algorithms will be discussed.

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1448: MODEL-BASED SOUND CODING

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Sound coding strategies for cochlear implants translate the incoming sound signal into parameters for the electrical pulse pattern to be delivered by the implant. This basic sound coding is accompanied by noise reduction and de-reverberation techniques which clean the sound signal prior to pulse processing, together achieving good performance in many listening situations. Without the explicit noise reduction, the common envelope coding onto fixed, high-rate pulse trains leads to problems with sound localization and listening in situations with noise and reverberation. One reason is seen in the lack of spectral and temporal coding precision due to interaction between stimulation pulses at the electrode-nerve interface and due to using high pulse rates.

In recent years, several models for the nerve's response to sequential electrical pulsatile stimulation, such as the S-BLIF model (Takanen and Seeber, CIAP 2017, DOI:10.5281/zenodo.4674564), have been developed which consider non-linear interactions to the pulses in a stimulation sequence due to adaptation, facilitation and refractoriness. I will report on a novel approach for a stimulation strategy which considers the nerve's non-linear response and hence deviates from classical deterministic sound coding. First, the processing order is inverse, as it does not start from the sound, but from the nerve's spiking response which is taken as a target. A nerve response model is placed in the loop of an optimization strategy which computes the pulse timings and amplitudes needed to evoke a target spike pattern. Different constraints can be implemented by penalizing the distance measure inherent to the optimization strategy. I will show examples of the optimization and discuss ideas how to overcome the problems posed by non-monotonic changes in the distance measure due to the omission of spikes in absolute refractory states.

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1470: EFFECTS OF TEMPORAL LIMITS ENCODER STRATEGY ON SPEECH-IN-NOISE RECOGNITION WITH BILATERAL COCHLEAR IMPLANTS: A SIMULATION STUDY WITH A GAUSSIAN-ENVELOPED TONE VOCODER

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Enhancing the temporal fine structure interaural time differences (TFS-ITDs) may improve spatial hearing of bilateral cochlear-implant (CI) users. The Temporal Limits Encoder (TLE) strategy seeks to enhance TFS-ITDs by downward transposition of mid-frequency band-limited channel information to a low-frequency range between the temporal pitch limits (~50 to 300 Hz) of CI users. This study investigates the performance of TLE in speech-in-noise recognition compared with a conventional enveloped-based advanced combinational encoder (ACE) in two experiments with a pulsatile Gaussian-enveloped tone vocoder simulating bilateral CIs.

In experiment 1, ten normal hearing (NH) listeners were tested for speech-reception-thresholds (SRTs) using TLE and ACE with two spatial conditions (one diotic target; two distractors with ITD = 0 μs or ITD = ± 625 μs) and two F0 conditions (two distractors with the same F0s range as the target or 100 Hz lower). Binaural intelligibility level differences (BILDs) were also calculated to measure binaural benefits. The TLE was implemented with a 16-of-22 symmetrical maxima selection, whereas the ACE used an 8-of-22 independent maxima selection. Moreover, the lower limit of the modulator was set to 200 or 300 Hz in TLE.

In experiment 2, eight NH listeners finished similar tasks as in experiment 1 but the ACE strategy was implemented with the same 16-of-22 symmetrical maxima selection with TLE so that the two strategies differ only in the amplitude modulator extraction methods, i.e., frequency downward transposition of TLE and temporal envelope extraction of ACE. The lower limit of the modulator was set to 200 Hz in TLE, and a non-vocoded condition was also tested to see the gap between NH and CI.

Results showed that:
1) In both experiments, TLE outperformed ACE by about 2.4 dB on average in the four spatial cue – F0 cue conditions, suggesting the frequency downward transposition facilitates speech-in-noise recognition.
2) Only in Experiment 2 which has symmetrical maxima selections, TLE showed BILD benefits of about 1.8 dB over ACE, which implies that ITD representation may be somewhat enhanced by TLE.
3) The binaural benefits of ACE strategy in Experiment 2 were poorer than that in Experiment 1 which has independent maxima selections, indicating that the combinational effects of increasing the number of maxima from 8 to 16 and selecting symmetrical maxima may not be helpful to improve ITD encoding.
4) In Experiment 1, the two versions of TLE with modulator lower limit of 200 Hz and 300 Hz performed closely in the SRTs and BILDs, suggesting that different lower frequency bound within the temporal pitch limits had little effect on the performance.
5) The F0 difference cue led to significant unmasking for both strategies, indicating capabilities of F0 coding in both strategies.
6) The non-vocoded SRTs were much lower than vocoded ones, confirming the fact that bilateral CI users suffer from poor speech-in-noise perception.

The findings in this study suggest that the TLE strategy has the potential to enhance TFS through its frequency downward transposition. The results also demonstrate that differences in several key features of ACE-like strategies for bilateral CIs could lead to significant performance differences with the simulation using the Gaussian-enveloped tone vocoder, which indicates the potentials of the vocoder.

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1474: A COMPARISON OF REAL-TIME FEASIBLE MASK ESTIMATION MODELS FOR REVERBERANT ARTIFACT REMOVAL IN COCHLEAR IMPLANT PULSE TRAINS

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Cochlear implant (CI) users experience far larger degradations in speech intelligibility in reverberant environments than their normal-hearing counterparts (Kokkinakis et al. 2011). Reverberation occurs when sound reflects off of surfaces in an enclosure, with reverberant reflections arriving at the listener at the same time as the direct speech signal. CI speech processing transforms the amplitude of frequency envelopes into discrete stimulus pulses across electrode channels. When the speech envelope is degraded by the simultaneous arrival of reverberant reflections, speech intelligibility is degraded. Particularly detrimental are late reverberant reflections which arrive at a listener after the termination of a phoneme and obscure the gaps between phonemes. Removing the reverberant artifacts between phonemes can restore speech envelope structure and significantly recover speech intelligibility for CI users in reverberation (Desmond et al. 2014; Kressner et al. 2018).

To remove reverberant artifacts between phonemes and restore the direct speech envelope, the technique of time-frequency (T-F) masking can be used to determine which time-frequency units of a degraded speech signal to retain or discard based on a measure of the local signal and interference energies within the speech envelope in frequency bands. In reverberant speech, T-F units between phonemes will contain predominantly late reverberant reflections and will be discarded. Typically, knowledge of the clean signal energy is unavailable to compute the ideal T-F mask, and so T-F mask values need to be estimated using information from the reverberant signal. Previous studies used statistical models to estimate mask values either by explicitly modelling late reverberant reflections (Hazrati et al. 2013a), leveraging a variance-based feature in an unsupervised manner (Hazrati et al. 2013b), or modelling vocal tract resonances using linear predictive coding (Hazrati and Loizou, 2013). While T-F masks estimated with these statistical models resulted in improvements in speech intelligibility in CI users, they required the use of non-causal information and empirical tuning of parameters, and the improvements shown were in limited, unrealistic reverberant settings. In addition, most of these approaches used time-frequency masking as a preprocessing step, using filter banks resulting in T-F decompositions with finer frequency resolution but coarser temporal resolution than that available in the CI stimulus. Due to the mismatch in spectro-temporal resolution, the T-F masks estimated with these models cannot be applied directly to the CI stimulus, imposing processing delays. Similar to T-F masking, we previously developed a machine learning algorithm to identify late reverberant reflections in CI pulse trains (Desmond, 2014). In this study, we develop additional machine learning models to estimate T-F masks with spectro-temporal resolutions compatible with the CI stimulus, enabling reverberation mitigation within the CI processing framework.

This study investigated the use of various machine learning models with different parametric complexities for estimating time-frequency masks for direct application within CI processing time frames using only causal features extracted from the reverberant signal. Our models are tested in reverberant conditions not encountered during training to test the algorithm's robustness. Preliminary results indicate models estimate masks with high accuracy when evaluated in reverberant conditions from the same room as used in training, although performance declines when tested on reverberant conditions from rooms not included during training. The algorithm performance, measured as the area under the receiver operating characteristic curve for the detection of speech-dominant mask values, will be reported. Additionally, we will report the resulting speech intelligibility of normal hearing subjects when tested with reverberant speech vocoded to simulate CI processing and mitigated by the investigated algorithms.

1488: LEVERAGING CLOUD COMPUTING RESOURCES TO ENHANCE CCI-MOBILE FUNCTIONALITY

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CCi-MOBILE is a software and hardware-based sound research platform intended to support the cochlear implant research community for both technology-based algorithm advancements, as well as scientific research studies. The research platform supports both in-lab/benchtop testing as well as take-home evaluation for naturalistic field studies. CCi-MOBILE currently supports both CI and hearing aid (HA) studies in unilateral, bilateral, and bimodal scenarios, and is compatible with clinical devices manufactured by Cochlear Corporation. To expand access and functionality of this research platform, a cloud-based infrastructure is proposed to leverage remote applications and to support remote opportunities. The goal is to expand access for CCi-MOBILE users as a laboratory community resource, including the current signal processing user base, and contribute to provide a mechanism to bring researchers and CI users together for improve interaction among current CCi-MOBILE users. This long-term effort is to develop a next-generation, flexible, open source, portable speech processor platform to be shared with the CI research community in a virtual/online manner. The cloud platform is categorized into 3 primary subsets: (1) data sharing among collaborating research institutions, (2) remote/virtual experimentation and data collection among researchers and CI participants, and (3) online crowdsourcing to promote CCi-MOBILE in both research and naturalistic field scenarios. Additionally, we aim to develop a secure, cloud-based service where researchers can share code and data complying with standard formats. In this work, the infrastructure of one of the subsets ‘CCi-Evaluate’ will be presented. This is the most challenging subset area in terms of infrastructure as it requires flexibility in adaptation to a variety of applications, tools, and algorithms developed within the research community. Examples of CCi-Evaluate will be provided to demonstrate a pipeline for conducting subject-experiments remotely utilizing Amazon Web Services (AWS) which offers many reliable and scalable cloud computing solutions. Several AWS applications such as Workspaces, AppStream, and AWS WorkDocs will be provided.

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1502: SPATIAL AND SPECTRAL CUE SENSITIVITY IN NORMAL HEARING LISTENERS USING COCHLEAR IMPLANT SIMULATIONS

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INTRODUCTION. Cochlear-implant (CI) users have poor spectral resolution correlated with speech perception in quiet and noise. Interleaved processing in CI users may improve spectral resolution and speech perception, but may impair spatial hearing (e.g., Aronoff et al. 2016). Interleaving frequency bands, however, has shown limited speech perception benefit in some individuals, possibly due to difficulty integrating cues across ears. The study had two primary aims: 1) determine how CI simulations with different interleaved cues affect spatial and spectral hearing, including in a multi-talker environment for speech perception and 2) determine how training affects speech perception performance and binaural benefit with interleaved CI simulations.

METHODS. Adults with normal pure-tone thresholds between .25-8kHz were recruited. The order of the vocoder conditions was randomized across participants for each aim.
Aim 1: The effects of interleaving cues across ears were tested using 12-channel vocoders with three types of interleaving in addition to traditional binaural vocoders: interleaved active electrodes/channels across ears, interleaved narrow input frequency filters with all electrodes active, and interleaved virtual narrow electrodes/channels (12 in each ear). Participants completed three experiments: 1) an adaptive spectral-temporally modulated ripple test (SMRT) for a threshold in ripples per octave, 2) sound localization in the rear hemifield using non-individualized head related impulse responses (HRIRs), and 3) speech recognition for functional use of spectral and spatial cues. Speech recognition thresholds (SRTs) were measured with co-located and spatially-separated target and masker sentences using the same HRIRs described above. The gender (voice pitch) of the maskers was varied to examine voice-pitch release from masking.

Aim 2: The effects of interleaving cues and upward spectral shifts were examined with four 12-channel vocoders: 1) identical cues across ears without an upward spectral shift of frequencies, 2) complementary/interleaved cues across ears without an upward spectral shift of frequencies, 3) identical cues across ears with an upward spectral shift of frequencies, and 4) complementary/interleaved cues across ears with an upward spectral shift of frequencies. Participants completed baseline speech testing in the same unilateral and bilateral co-located and spatially-separated conditions described above, 45 minutes of training with auditory vowels and consonants with feedback, and repeated speech testing in one and both ears to measure change in performance from baseline and binaural integration. Outcome measures were the change in SRT from baseline to post testing as well as the change in percent correct in vowel and consonant recognition over time.

RESULTS. Preliminary data revealed that spectral resolution increased with interleaving, but was primarily a monaural effect with little binaural integration for better spectral resolution. There was little speech perception benefit (<1 dB) with both ears in a co-located condition, even with interleaving and complementary information across ears, indicating combining interleaved speech cues might be difficult. Degree of error for localization was slightly worse with interleaved frequency bands. Finally, spatial release-from masking (SRM) was significant but might be somewhat impaired with interleaved frequency channels across ears.

CONCLUSION.Interleaving cues across ears can improve monaural spectral resolution but might not improve binaural speech recognition. The lack of binaural benefit from interleaved cues could be due to disrupted spatial hearing cues or difficulty integrating interleaved speech across ears. Speech training might help to improve monaural and binaural speech recognition with interleaved CI processing.

1506: CCI-MOBILE: ANALYSIS AND EVALUATION OF NON-LINGUISTIC SOUND ENHANCEMENT FOR COCHLEAR IMPLANT RECIPIENTS

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Sensorineural hearing loss is a prevalent condition for the world's population (ranging from 0.07% to 5.2% across countries) that can be characterized by reduced functionality of the cochlea, auditory nerve, or central auditory pathways [1]. Cochlear Implants (CIs) are the most successful neural prosthesis that directly stimulates the auditory nerve, thereby bypassing compromised/injured hair cells of the cochlea, to provide salient acoustic coded information for speech perception. CI research is typically focused on advancing speech perception as it poses greater challenges, especially in noisy, reverberant, or time-varying diverse environments. Several studies in music and environmental sound perception among CI users seem to suggest that existing CI sound processing strategies are designed to process speech, (i.e., linguistic sounds). However, they may not be as effective in processing non-linguistic sounds, (i.e., sounds which cannot be described using phonemes, namely: music, environmental sounds (animals, nature sounds – wind, etc., context sounds (home appliances, transportation – car, bus, bicycle,etc.), and others. In this study, a framework is proposed to enhance non-linguistic sound perception among CI users. A Nonlinear Recursive Least Squares (NRLS) estimation is used to determine an optimal filter with sub-band gains that boost dominant spectro-temporal features correlated with subjective percepts of non-linguistic sounds, namely: (i) sound pleasantness, (ii) complexity, and (iii) recognizability. Four sets of optimal filter structures were designed corresponding to four alternate spectro-temporal boosting methods: (1) Normalized Length Density Fractal Dimension (NLDFD), (2) harmonicity, (3) mean peak, and (4) the mean spectral centroid. For every spectro-temporal boosting method and non-linguistic sound class/category, an optimal filter structure is created/estimated. These estimated optimal filter structures are then integrated within a standard CI processing pipeline to produce perceptually enhanced audio sequences for assessing the listening experience of non-linguistic sounds. Audio stimuli from the ESC-50 database were used to perform listener evaluations with CI users and Normal Hearing (NH) listeners in simulated CI conditions. CI processing was facilitated using the CCi-MOBILE Research Platform[3] and simulated CI conditions generated using the Braeker Vocoder, a CI simulator. The analysis and evaluation were carried out by analyzing CI electrodograms and subjective perception scores of sound pleasantness, complexity, and recognizability. This proposed framework for non-linguistic sound enhancement for CI users is suggested to be the first investigation aimed at improving non-linguistic sound perception among CI users. The proposed framework is scalable and also contributes towards improved environmental awareness and music appreciation among CI listeners. The findings from this study could also be applied to improve speech communication in various environments with background noise, distortion, or competing sound-scape properties.

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1511: THE COCHLEAR IMPLANT HACKATHON: SCALABLE WEB-ENABLED AUDITORY PERFORMANCE JUDGING PLATFORM

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Researchers worldwide are actively pursuing signal processing strategies to improve the auditory performance of cochlear implant users. Typically, each independent research group attempts to demonstrate improvements in CI performance using a wide variety of auditory tasks. One critical limitation of this approach is that the diverse strategies generated from each independent group are rarely directly compared to one another in any standardized fashion. To overcome these limitations as part of the Cochlear Implant Hackathon (cihackathon.com), we devised a set of web tools that would theoretically enable thousands of signal processing algorithms to be directly compared on a common set of tasks. Groups are provided with audio files representing words, sentences, sentences in noise, or music. Each group uses their signal processing algorithm to generate a matrix file containing electrode activation information. An electrodogram-based vocoder is then used to convert matrix files into audio output files. The resulting audio outputs are ranked in two rounds. In the first round, audio outputs are ranked by judges on a scale of one to 10. In the second round, an arbitrary cutoff is selected and top performers from the first round are judged by pairwise comparison. The web tools feature secure logins for privacy and real-time leaderboard functionality. This platform serves as a model on which future community-wide competitions could enable hundreds or even thousands of CI signal processing algorithms to be directly compared via acoustic vocoder (or other) simulations.

Bilateral, Binaural, Bimodal, EAS Stimulation – Invited and Featured Talks + Posters

Invited Recorded Talk

1517: FREQUENCY-TO-PLACE MISMATCH IN ELECTRIC-ACOUSTIC STIMULATION DEVICE USERS: EFFECTS ON SPEECH RECOGNITION AND MODIFIED MAPPING PROCEDURES

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Cochlear implant (CI) recipients with hearing preservation experience improved speech recognition with electric-acoustic stimulation (EAS) as compared to preoperative performance with a hearing aid or postoperatively when listening with the CI-alone. Despite the trends for better performance with EAS, outcomes across individuals are variable. These individual differences may be due in part to the wide variability across CI recipients in the angular insertion depth of the electrode array, which is related to the array design, cochlear morphology, and surgical approach. The EAS default mapping procedure does not consider array placement relative to the cochlear place frequency, resulting in frequency-to-place mismatch in the majority of EAS users. Mismatch has been shown to negatively impact the speech recognition of CI-alone users, although some CI-alone users demonstrate the ability to acclimate to mismatch with prolonged listening experience. For EAS users, mismatch may be particularly problematic because acoustic stimulation is resolved at the natural cochlear place, while the electric stimulation is spectrally-shifted. Better speech recognition may be observed for EAS users listening with a place-based map that aligns the electric filter frequencies to the cochlear place frequency to eliminate mismatch. The present investigation assesses the speech recognition of EAS users listening with either default or place-based maps within the initial months of device use to determine the influence of mismatch on early performance growth.

Adult CI recipients with low-frequency hearing preservation were randomized to receive maps with either the default filters or place-based filters at initial EAS activation. Subjects listened exclusively with either default or place-based maps and completed speech recognition tasks at initial EAS activation, and at 1, 3, and 6 months post-activation. Speech recognition tasks included vowel recognition and consonant-nucleus-consonant (CNC) word recognition. The vowel recognition stimuli were presented via direct audio input at a comfortably loud volume. The CNC words were presented in the sound field at 60 dB SPL with masking presented to the contralateral ear, when warranted. Performance for both tasks was scored as the percent correct. The frequency-to-place mismatch at 1500 Hz was estimated based on post-operative imaging.

Preliminary data suggest poorer speech recognition with greater magnitudes of mismatch. These data patterns were observed at the initial EAS activation interval and persisted through the 6-month post-activation interval. Investigation is ongoing to confirm these preliminary trends and to determine whether EAS users with greater magnitudes of mismatch eventually acclimate to the spectrally-shifted information and achieve similar speech recognition as observed for EAS users with little or no mismatch.

Invited Recorded Talk

1425: A DEEPER UNDERSTANDING OF BINAURAL SENSITIVITY IN CHILDREN WITH BILATERAL COCHLEAR IMPLANTS REVEALED THROUGH EYE GAZE

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For both safety and effective communications, spatial hearing is critical for children when they navigate everyday auditory environments. For children with severe-to-profound hearing loss, bilateral cochlear implantation (BiCI) has become the standard of care worldwide, with significantly notable benefits from having two CIs over one CI. However, their performance with BiCIs is still poorer than their normal-hearing (NH) peers on various measures including spatial hearing tasks. This gap in performance is considered to be caused by the practice of fitting each CI separately and the fact that today's clinical processors do not have obligatory coordination of the timing of inputs to the electrodes across the ears. Thus, interaural time and level difference cues (ITD and ILD, respectively) that play a major role in facilitating functional spatial hearing outcomes are not conveyed at the cochlear arrays with fidelity.

Our group has previously used research interfaces to stimulate select pairs of electrodes at 100 pulses per second, and tightly control the coordination of stimuli across the ears to assess sensitivity to ITDs and ILDs in children who listen with BiCIs. When we assessed just-noticeable-difference (JND) thresholds using a two-alternative forced-choice task, most children showed sensitivity to ILDs but very few were sensitive to ITDs (Ehlers et al., 2017, JASA vol. 141). More recently, we have been able to assess envelope (ENV) ITDs using clinical processors with a carefully designed, novel acoustic signal – a complex that consists of eight transposed tones with an amplitude modulation of 30 Hz and center frequencies at electrodes numbered 4-11 in each child's clinical map. This complex, when presented to Cochlear Nucleus processors running the Advanced Combination Encoder (ACE) strategy, will elicit stimulation in the eight targeted electrodes and amplitude modulate the electrical pulses at 30 Hz without distortion by the sound coding strategy. Using this stimulus, 9 of 11 children with BiCIs have demonstrated ENV ITD sensitivity with JND thresholds ranging from 212-880 µs (Peng et al., 2019, CIAP).

In addition to measuring JND thresholds, we simultaneously recorded the decision-making process as revealed by the time-course of eye gaze movements as children performed the psychophysical task. The eye gaze data revealed longer latency and higher uncertainty in decision-making as the magnitude of a binaural cue became less salient. Because an acoustic stimulus was used, it has enabled us to compare the time-course of decision-making of children with BiCIs (8-17 years old), NH children (8-13 years old), and NH adults. Compared with NH adults, NH children showed adult-like JNDs, and took the same amount of time to arrive at a decision. However, children showed greater uncertainty with more frequent eye gaze switches between the two visual alternatives (i.e., left vs. right). The eye gaze behaviors from children with BiCIs revealed a different pattern compared to NH children. These findings suggest that there are both development- and device-related factors in their detection of binaural cues in the signal envelope for children who listen with BiCIs. Children with BiCIs may be taking a "wait-and-see" approach—taking a longer time to initiate a decision when the binaural cue becomes less salient.

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Featured Recorded Talk:

1344: HEMISPHERE-SPECIFIC DEGRADATIONS IN NEURAL ITD PROCESSING FOLLOWING SINGLE-SIDED DEAFNESS (SSD) ASSOCIATED WITH ALTERATIONS IN TEMPORAL RATE CODING

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Unilateral cochlear implants (CIs) allow the functional restoration of binaural hearing in subjects with single-sided deafness (SSD). However, speech perception in noise and directional hearing in these subjects (‘SSD-CI users’) is typically poorer than in normal-hearing listeners. Moreover, improvements in directional hearing in SSD-CI users are primarily based on interaural level differences rather than interaural time differences (ITDs). One possible explanation for these deficits is that SSD may disrupt the hemispheric balance of binaural auditory circuits that support ITD discrimination. Also, asymmetric degradations in temporal repetition rate coding may adversely affect the acuity of electric ITD processing.

Here, we characterized the responses of single neurons in the inferior colliculus (IC) to electric ITDs in unilaterally deafened, adult gerbils (SSD duration 15 days) that had been bilaterally implanted with round window electrodes. This approach largely excluded the possibility of between-ear mismatches in activation site as a confounding factor in binaural processing and allowed us to directly compare ITD coding to biphasic electric pulse trains between hemispheres. To test for correlations between ITD processing and neural temporal coding, interaural differences in response strength and temporal precision (vector strength, VS) to monaural pulse trains of increasing rates were quantified in both hemispheres. Normal hearing (NH), adult gerbils served as controls.

The incidence of ITD-sensitive neurons was similar for NH and SSD animals. Among ITD-sensitive neurons, SSD led to degradations in the degree of ITD sensitivity and neural ITD discrimination thresholds in both hemispheres. However, changes were particularly pronounced in the hemisphere contralateral to the deafened ear. In parallel, population ITD coding in SSD animals was highly asymmetric between hemispheres. As a result, the intercept of average rate-ITD functions from both hemispheres shifted far outside the physiological range for ITDs. According to ‘two-channel’ models of sound localization, such imbalances in neural ITD coding between the two hemispheres are predictive of poor acuity in ITD discrimination performance. Moreover, in the hemisphere contralateral to the deaf ear, response strength, but not temporal precision (VS), to stimulation of the deaf ear was significantly reduced, resulting in a loss of contralateral dominance typically observed in NH animals.

In summary, adult-onset SSD triggers bilateral and highly asymmetric degradations in ITD processing that are associated with hemisphere-specific alterations in temporal rate coding. Similar imbalances in binaural integration between hemispheres may be a neurophysiological basis for clinical deficits in unilateral hearing loss, such as impaired hearing in noise and poor directional hearing.

Supported by DFG VO 640/2-2.

Featured Recorded Talk:

1366: SOUND LOCALIZATION AND SPATIAL RELEASE FROM MASKING IN BILATERAL COCHLEAR IMPLANT LISTENERS WITH LINKED AUTOMATIC GAIN CONTROLS

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Bilateral cochlear implant (BI-CI) listeners experience difficulty localizing sounds in their environment and understanding speech in noisy backgrounds. Both tasks are potentially improved with higher fidelity of interaural level differences (ILDs), a binaural cue accessible to BI-CI listeners. Automatic gain controls (AGCs) are a form of output-limiting compression traditionally implemented independently at each processor, leading to reduced or lost ILDs. Linking AGCs across the two ears is one way that could better preserve ILDs. The effects of linked AGCs on sound localization accuracy and bilateral benefits to speech understanding (specifically, summation, head shadow, and squelch) were examined in BI-CI listeners in a pair of experiments. It was hypothesized that linked AGCs would improve localization and bilateral benefits compared to those with independent AGCs.

In the first experiment, localization accuracy was measured in 10 BI-CI listeners using research processors with linked and independent AGC programs. Sounds were presented from an eleven-loudspeaker array (15-degree resolution from -75 to +75 degrees). Localization accuracy was measured for broadband white noises, speech-spectrum-shaped noises, speech-modulated noises, and speech stimuli (sentences and words) at 75 dB SPL (with a ±5-dB range of level-roving). In the second experiment, speech understanding was measured in 9 BI-CI listeners using research processors with linked and independent AGC programs. Listeners attended to target speech (0 degrees) amidst a single-talker interferer under spatial (interferer at -90, 0, or +90 degrees) and ear (left, right, or both) manipulations to facilitate calculation of bilateral benefits. Talker locations were simulated under headphones using head-related transfer functions and stimuli were presented at an overall level of 75 dB SPL. In the first experiment, as expected, localization errors were significantly reduced with linked AGCs, particularly at larger angles, suggesting that better preservation of ILD cues leads to a perceptual benefit to BI-CI listeners. This benefit was smaller for speech-modulated noises and speech than for broadband white and speech-spectrum-shaped noises. In the second experiment, linked AGCs did not significantly improve speech understanding with a competing talker in this paradigm, but there was also no detriment observed with their use.

These studies show that benefits with linked AGCs are stimulus- and location-dependent. Overall, results suggest that linked AGCs have the potential to improve spatial hearing in BI-CI listeners.

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Featured Recorded Talk:

1373: PROVIDING ANCHORS FOR MEASURING BINAURAL FUSION WITH COCHLEAR IMPLANT USERS

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Accurately measuring binaural fusion can be challenging, especially with individuals with bilateral cochlear implants (CIs), who do not have an accurate reference point for a fused sound. The goal of this study was to validate a measure that uses unilateral stimulation to create a fused reference point, facilitating accurate measurement of fusion for bilateral stimulation for CI users.

Seven bilateral CI users participated in this study. There were eight stimuli, each consisting of a one second vocalizations of /a/, with each stimulus produced by a different individual. Stimuli were randomly presented to either the right, left, or both ears via direct connect. For each stimulus, participants used a dial to change the location of the stimulus and to indicate the size of the image in their head resulting from the stimuli, including whether it consisted of one or two images. The participants were not told that the stimuli would sometimes be delivered to only one ear. There was a total of 72 stimuli, with an equal likelihood of the stimuli being delivered to the right ear, left ear, or both ears.

Participants generally had correctly lateralized and relatively punctate (i.e., originating from a small, discrete location in space) percepts when the stimuli were presented to only one ear, indicating that the unilateral stimuli presented an anchor for a punctate, unitary sound. In contrast, the image was centered but more diffuse when the stimuli were presented to both ears simultaneously. For approximately half of the participants, these diotic stimuli were perceived as two distinct images, one at each ear.

The results suggest that a unilateral stimulus can be used to provide an anchor for measuring binaural fusion. Binaural fusion can then be measured as the difference between the binaural and the unilateral responses.

Funding for this study was provided by a Campus Research Fund grant from the University of Illinois at Urbana-Champaign

Featured Recorded Talk:

1320: BIMODAL INTERACTIONS BETWEEN ACOUSTIC AND ELECTRIC BINAURAL STIMULATION IN AUDITORY CORTEX OF AWAKE MARMOSETS WITH UNILATERAL COCHLEAR IMPLANT

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Patients with single-sided deafness (SSD) have impaired listening abilities, including speech perception in noise and sound localization that depend on binaural information. Unilateral cochlear implant (CI), an FDA-approved treatment for SSD patients, has been shown effective in improving binaural listening abilities of SSD-CI users. However, little is known about how the brain integrates acoustic and CI inputs from both ears at the single-neuron level. In this study, we used unilaterally deafened marmosets implanted with CI electrodes in the deafened ear (the other ear was left intact) as the animal model to investigate cortical processing of binaural acoustic and CI inputs. We found that acoustic and CI binaural stimulation resulted in both facilitation and suppression in the primary auditory cortex of marmosets. In contrast to binaural interactions between acoustic inputs from two normal hearing ears, hemispheres contralateral or ipsilateral to the CI ear showed asymmetries in bimodal interaction patterns. Bimodal suppressions were dominant in the hemisphere ipsilateral to the CI ear, whereas both bimodal facilitations and suppressions were found in the hemisphere contralateral to the CI ear. Further analyses showed that properties of bimodal interactions depend on CI electrode configuration, and can be affected by sound or current levels of acoustic or CI stimuli. Taken together, our results provide evidence on bimodal interactions of binaural acoustic and CI inputs in the primary auditory cortex and insights into how CI may facilitate the recovery of binaural information in SSD-CI patients.

1382: A STATE-OF-THE-ART IMPLEMENTATION OF A BINAURAL COCHLEAR IMPLANT SOUND CODING STRATEGY INSPIRED BY THE MEDIAL OLIVOCOCHLEAR REFLEX

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Objectives: Many cochlear implant (CI) users find it hard and effortful to understand speech in noise with current clinical devices. Previous studies have shown that the MOC strategy (a binaural sound processing strategy inspired by the contralateral medial olivocochlear reflex) can improve speech-in-noise recognition for CI users. All reported evaluations of this strategy, however, were restricted to a single conversational speech level and to implementations that omitted automatic gain control (AGC) and fine-structure (FS) processing, two characteristics that are standard in some current CI devices. To better assess the potential of the MOC strategy in combination with contemporary CI sound-coding strategies, here we compare speech-in-noise intelligibility and listening effort with and without MOC processing in combination with linked AGC and FS processing for a wider range of speech levels than has been tested so far.

Design: Speech-in-noise recognition and listening effort were compared for sounds processed through MED-EL's FS4 sound-coding strategy without and with binaural MOC processing with slow contralateral control of compression (MOC3-FS4). Seven bilateral users of MED-EL CIs participated in the study. Speech reception thresholds (SRTs) were compared for sentences in steady and fluctuating noise, for various speech levels, in bilateral and unilateral listening modes, and for multiple spatial configurations of the speech and noise sources. Word recall scores and verbal response times in a word recognition test were used as proxies for listening effort and were compared for the two strategies in quiet and in steady noise at +5 dB signal-to-noise ratio (SNR) and at the individual SRT.

Results: In bilateral listening and in steady noise, mean SRTs across participants were always equal or better with the MOC3-FS4 than with the standard FS4 strategy. The mean SRT improvement across the range of speech levels and spatial configurations was 0.8 dB SNR and the largest benefit was 2.2 dB SNR. In fluctuating noise, SRTs were equal for the two strategies. In unilateral listening, mean SRTs across all spatial configurations was 1.7 dB better for the MOC-FS4 strategy than for the FS4 strategy. Word recall scores and verbal response times were not significantly different for the two strategies in any of the conditions tested.

Conclusions: MOC processing can be combined with linked AGC and FS4 sound coding. Compared to using FS4 processing alone, combined MOC3-FS4 processing can improve the intelligibility of speech in noise without affecting listening effort.

Keywords: Cochlear implant; binaural sound processing strategy; speech-in-noise intelligibility; listening effort.
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1389: SYNCHRONIZATION OF AUTOMATIC GAIN CONTROL ENHANCES SPATIAL HEARING IN BIMODAL COCHLEAR IMPLANT USERS

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Users of a cochlear implant often profit from a conventional acoustic hearing aid in the contralateral ear. These two modes of hearing have their own benefits: electrical hearing is optimized for speech perception, while acoustical hearing provides additional information on pitch and melody. However, the benefit of combined, bimodal hearing on spatial perception and speech understanding in noise is often limited. These tasks require binaural integration and rely on interaural low-frequency timing and high-frequency level differences (ITD, ILD). Both cues are reduced or perturbed in bimodal listeners.

One source of distortion for ILD cues is the Automatic Gain Control. In conventional devices, activation parameters for Automatic Gain Control (AGC) typically differ between CI and hearing aid. Previous work by Veugen et al. (Hearing Res 336:72, 2016) showed a benefit in speech understanding and localization behavior by matching the AGC settings of the hearing aid with those of the CI processor. However, in that study the AGC in both devices still acted independently, causing asynchronous activation. This has been shown to lead to a distortion of ILDs for loud sounds resulting in shifts of the perceived localization towards the side opposite to stimulation. We show that AGC synchronization reduces localization errors for loud broadband sounds compared to the non-synchronized condition. As expected, localization of sounds presented below AGC threshold remained unaffected. In addition, there was a benefit in speech-in-noise recognition with AGC synchronization when loud noise was presented towards the HA side.

We conclude that synchronizing activation of AGC between bimodal devices can be beneficial for binaural integration.

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1394: THE THREE DIMENSIONS OF COCHLEAR-IMPLANT INTERAURAL MISMATCH

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Hearing with two ears can provide tremendous improvements in sound localization and understanding speech in the presence of competing sounds. While bilateral cochlear-implant (BI-CI) and single-sided-deafness cochlear-implant (SSD-CI) users experience some of these benefits, they are diminished relative to normal-hearing listeners. The causes are many, but they are all factors that work against the exquisitely precise encoding of interaural differences that occurs at the brainstem. Here we discuss these problems in terms of three different dimensions of mismatch between the ears – frequency, timing, and level. While interaural frequency and timing mismatches have received the most attention date, we present data to suggest that interaural level mismatch may be at least as important.

First, there is interaural frequency mismatch, where the place of stimulation differs across the ears because of differences the insertion depths of the individual electrode contacts. This type of mismatch distorts spatial perception, biasing the sound perception towards the ear with the more basal stimulation. Second, there is interaural timing mismatch, mostly relevant for SSD-CI users because of the different processing time from the sound processor compared to the acoustic ear. Third, there is interaural level mismatch, where bilateral stimuli that are equally loud when presented sequentially produce a distorted spatial map when presented simultaneously. It is presently unclear what causes interaural level mismatch, but it may be related to interaural asymmetries in neural survival, the electrode-to-neural interface, or modality (i.e., acoustic versus electric stimulation).

We have found that interaural frequency mismatch is common in SSD-CI listeners (~150° or 6 mm on average at the apex) and uncommon in BI-CI listeners (~25° or 1 mm on average). It was our expectation that correcting for interaural frequency mismatch in SSD-CI listeners would improve spatial hearing. While we did find improvements for some SSD-CI subjects, benefits were modest. Through this process, we discovered that manipulating the stimulus level – a basic requirement anytime a CI listener receives a new map – had a larger than expected impact on outcomes. Therefore, interaural level mismatch may be at least as important as interaural frequency mismatch. We argue for increased attention to this dimension of mismatch, including the identification of its causes and consequences, and an examination of whether it can be addressed through training and plasticity.

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1400: SENSITIVITY TO INTERAURAL TIME DIFFERENCE AND TEMPORAL PITCH IN DUAL-ELECTRODE STIMULATION: EFFECTS OF BETWEEN-ELECTRODE DELAY, TONOTOPIC SEPARATION, AND STIMULUS TYPE

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Cochlear-implant (CI) listeners struggle in everyday situations that require selective hearing. Better access to source segregation cues, particularly interaural time differences (ITDs) and temporal pitch, may improve selective hearing. However, even for a single broadband source, channel interaction can be assumed to impact the access to these temporal cues.

The amount of channel interactions is determined by the stimulation paradigm, in particular, the number of stimulated electrodes, the per-electrode pulse rate, the electrode stimulation order, and the between-electrode delay. High-rate paradigms usually convey ITD and temporal-pitch cues via the temporal envelope. More recently proposed low-rate paradigms convey those cues via the pulse timing. While high-rate paradigms potentially provide more detailed speech information, they likely produce more channel interactions as compared to low-rate paradigms.

In this study, we investigated the impact of various stimulation parameters on channel interactions by measuring the sensitivity to ITD and temporal pitch in CI listeners using matched setups. The stimuli consisted of a target electrode (located in the center of the array) and a flanker electrode (located on either side of the target). Two tonotopic separations were chosen based on the listener’s forward-masked spatial tuning curve. For pitch, to create maximal channel interaction, electrodes adjacent to the target were selected as narrow flankers. Wide flankers were chosen to provide minimal channel interaction while being as close as possible to the target. For ITD, target and flanker electrode candidates were determined per ear as described for pitch. Interaural electrode pairs were then finally selected in an ITD-sensitivity pretest. Per electrode, stimuli were either unmodulated 100-pps pulse trains or 1000-pps pulse trains with a 100-Hz amplitude modulation and a modulation depth of 0.3. The modulated stimuli were tested both with and without additional pulses placed with short inter-pulse intervals at modulation peaks. Six delays between target and flanker were tested in the range of one (modulation) period. In addition, single-electrode ITD and temporal-pitch sensitivity was measured for all stimulus types and electrodes. Each person was tested with a single, individually determined ITD and/or frequency difference. Throughout all tests, experimental conditions were loudness-balanced and, in case of ITD, image-centered.

Low-rate stimulation yielded generally higher sensitivity than high-rate stimulation. For narrow spacings, our results show a systematic effect of the between-electrode delay, being symmetric around 50% of the modulation period but depending on the stimulus type in its strength. For wide spacings, the delay effect was highly listener-specific with some listeners showing an effect similar to narrow spacings and other listeners showing no effect at all. Differences between narrow and wide spacings reflect the amount of channel interactions. Asymmetries between apical and basal flankers as well as similarities and differences between ITD and temporal pitch will be discussed.

Our results have implications for improving existing and designing new stimulation paradigms aiming at improving timing sensitivity and, ultimately, selective hearing in CI listeners.

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1406: A MIXED-RATE STRATEGY FOR REAL-TIME DELIVERY OF INTERAURAL TIME DIFFERENCES TO COCHLEAR IMPLANT USERS

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Bilateral cochlear implant (BiCI) users do not perform as well as normal hearing (NH) listeners on spatial hearing tasks such as sound localization. This can be partially attributed to the fact that BiCI listeners have limited access to interaural time differences (ITDs) using their unsynchronized clinical processors. Prior work has demonstrated that BiCI listeners are able to discriminate and lateralize (localize within the head) using ITDs when stimuli are provided via synchronized, highly-controlled desktop research processors. ITDs can be encoded either directly to the timing of low-rate pulse trains or to a slow envelope modulation on high-rate pulse trains. Sensitivity to ITDs is typically observed when either the pulse timing or modulation is below 300 Hz. However, clinical stimulation rates used for good speech understanding are too fast to yield good ITD sensitivity, around 1000 pulses per second (pps). Previous work has shown that mixed-rate stimulation, in which high and low rates presented on different pairs of electrodes, can result in good ITD sensitivity and lateralization with the potential for preserving speech understanding. However, the utility of envelope modulations embedded in a mixed-rate strategy has yet to be examined. Here, we hypothesize that when coherent ITD cues are provided in both the signal envelope and individual pulses, ITD sensitivity will be maximized when listening with the mixed-rate strategy.

To test this hypothesis, we implemented a real-time mixed-rate stimulation strategy that provides ITD cues via the timing of low-rate pulses and envelope modulations of high-rate pulses. Our novel mixed-rate strategy is based on the principles of continuous interleaved sampling and utilizes five high-rate (1000 pps) and five low-rate (125 pps) channels, whereby low-rate channels are delivered at an integer factor of the high-rate channel stimulation rate. ITDs are estimated from the incoming acoustic signal using a cross-correlation of the left and right ear signals. This strategy was implemented using the CCi-MOBILE research device, a portable and synchronized bilateral research processor.

Stimuli consisted of ten sinusoids that had an ITD of either -800 or +800 microseconds. The frequency of each of the sinusoids were the center frequencies of the ten channels available in the strategy. These acoustic stimuli were processed using either the mixed-rate strategy or an all-high strategy (high rate on all channels), and were streamed using the CCi-MOBILE. Three conditions were tested: 1) mixed-rate strategy with no envelope modulations, 2) mixed-rate strategy with 125 Hz envelope modulations on the high-rate channels, and 3) all-high strategy with 125 Hz envelope modulations on each channel. Based on our hypothesis, we predict that a mixed-rate strategy may yield improved ITD sensitivity if the ITD is available in both the low-rate channels and in the envelope modulations of high-rate channels, as compared to only in low-rate channels or envelope modulations. Participants were asked to report the perceived intracranial lateral location of the sound. Results will be presented in the context of how ITD cues are encoded and delivered by the strategy, and how they map to a lateral location within the head. The results of this study will inform the development of further binaural signal processing strategies and potentially lead to new clinical devices that can deliver synchronized binaural cue information.

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1407: THE INFLUENCE OF DYNAMICALLY VARYING INTERAURAL TIME DIFFERENCES ON AUDITORY OBJECT FORMATION AND LATERALIZATION IN BILATERAL COCHLEAR IMPLANT LISTENERS

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In complex acoustic environments normal hearing (NH) listeners, interaural time differences (ITDs) help separate the location of a target sound from that of a distracting sound. This is because the NH auditory system places greater perceptual weight on onset ITD cues than on later-arriving, ongoing ITD cues to facilitate the formation of stable and localizable auditory objects. For listeners with bilateral cochlear implants (BiCIs), ITDs are not as readily accessible due to: 1) poor neural survival in one or both ears, 2) lack of control over timing to the inputs in both ears, 3) high rates of stimulation used in clinical processors (~1,000 Hz). Further, cues that allow for good auditory object formation, such as salient onsets and fundamental frequency are poorly encoded in CIs. Recent data in our lab suggests that when BiCI listeners are presented with an electrical signal that is intended to represent different auditory 'objects' in space, they experience difficulties perceptually segregating and lateralizing these objects. We hypothesized that this difficulty stems from the lack of consistent onset ITD cues, and that by increasing the number of electrical pulses with a consistent ITD at the onset, BiCI listeners would exhibit changes in the perceptual weight of onset ITDs to lateralize and hear coherent sound objects. Using synchronized research processors, trains of biphasic electrical pulses (100 pulses-per-second, 300 ms duration) were presented to an interaural pair of electrodes determined by a pitch-matching task. The leading portion of the pulses had an ITD of either 0, -800 µs or +800 µs, and the number of leading pulses varied trial by trial (between 1 and 30 pulses). The trailing pulses had a dynamically-changing ITD that on average varied by ±40 µs from magnitude of the ITD in the leading portion and pointed either to the same or opposite hemifield as the leading ITD. Listeners responded by indicating the number of perceived auditory objects, ranking them from most to least dominant, and the location(s) of these object(s). The proportion of sounds reported as a single object vs. two objects was taken as a measure of auditory object formation. Results showed that BiCI listeners reliably identified and lateralized an auditory object in the direction of the onset ITD as the number of pulses with a consistent ITD increased. At least five pulses with consistent ITDs were required in the leading portion when leading and trailing portions corresponded to locations in opposite hemifields. However, when ITDs in the leading and trailing portions corresponded to the same hemifield, the auditory object was lateralized in that direction regardless of number of consistent ITD pulses in the leading portion. Perceived object formation appeared to be unrelated to the number of leading pulses. Dominant auditory object were always reported in the direction of the leading, consistent ITD. Secondary objects, if perceived, were reported towards the direction of the trailing, dynamic ITD. These findings suggest that binaural coding strategies that aim to present ITD cues in the electrical pulse train may need to consider encoding at least five pulses with consistent ITDs at the onset of a stimulus, so that sound objects can be correctly localized in complex auditory environments.

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1432: FITTING CONSIDERATIONS FOR BIMODAL AND SINGLE SIDED DEAF COCHLEAR IMPLANT USERS

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When listening with a cochlear implant through one ear and acoustically through the other, binaural benefits and spatial hearing abilities are poorer than in other bilaterally stimulated configuration. An increasing number of patients receive a cochlear implant even though they have functional hearing in their other ear. For these patients it may be possible to facilitate azimuthal sound source localization which relies on the encoding of interaural time and level differences - the latter is generally the perceptually more relevant of the two in electric hearing. In practice, however, it is not at all guaranteed that they can solve basic localization tasks, e.g. is the car approaching from the left or the right. Our working hypothesis is that azimuthal localization is only possible if the interaural differences are encoded in the response of subcortical binaural neurons. From this starting point several consequences can be derived for a binaural fitting process. Primarily, that a frontal sound source should generate an interaurally matched stimulation of these neurons in terms of intensity and latency. As binaural neurons only compare tonotopically matched inputs the stimulation also has to match in this respect. We evaluate theoretically, if and to which degree existing mismatch measurement and mismatch compensation strategies target our neuro-centric definition of mismatch and compare their general applicability in terms of precision, speed, and other practical factors. The ideal methods differ for different patient groups and depend on the available time. A holistic mismatch compensation is not realistic at the moment, but even a partial optimization can be expected to lead to large spatial hearing improvements in some patients. However, even with a hypothetical ideal fitting the performance is not expected to exceed a good bilateral cochlear implant user.

1436: OFF-THE-EAR VS. BEHIND-THE-EAR BILATERAL CI PROCESSORS: THE EFFECT ON SPATIAL HEARING

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As patients and families explore options for cochlear implant processor selection, providing evidence regarding performance is essential to set realistic expectations for listening goals.

Research indicates that off-the-ear cochlear implant processors have been rated higher through subjective assessment by recipients in the areas of aesthetics, comfort, and overall hearing performance. Comparison of words in quiet and sentences in noise have yielded no statistical significance between off-the-ear and behind-the-ear processors; however, measures of speech recognition thresholds found behind-the-ear processors to have improved audibility compared to that of off-the-ear processors. This study seeks to further investigate the differences between these types of processors.

Given that microphone location of the off-the-ear processor is dependent upon surgical placement of the receiver, it is hypothesized that microphone location may impact performance compared to on-the-ear processors within subject.

This study explored performance between the Cochlear CP910 Nucleus 6/CP1000 Nucleus 7 processors and CP950 Kanso processors in measures of localization and listening in noise in bilateral CI recipients. Experienced adult bilateral CI recipients were recruited from The University of Tennessee Hearing and Speech Center. Research processors (1-set of N6/N7 and 1-set of Kanso processors), were programmed using each subject's established MAP settings. The distance between the ear canal and the implant magnet as well as the angular elevation from horizontal were noted for each participant to ascertain location of processor microphones relative to the ear canal. Subjects were evaluated using research processors (on-the-ear processors and off-the ear processors) using the Sound Source Identification Procedure to measure localization acuity and Children's Realistic Index of Speech Perception (CRISP) to measure speech perception

1438: HAVING A WEAKER EAR IN BILATERAL CI: SPATIAL SPEECH PERCEPTION AND RELATIVE LOCALISATION IN VOCODER SIMULATIONS

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Bilateral cochlear implants (CIs) are thought to be beneficial for spatial speech perception and localisation. Spatial hearing relies on the use of interaural differences in time (ITDs) and level (ILDs). Bilateral CIs are often implanted sequentially. In quite a few cases, the second implant is more difficult to fit, being perceived as too soft, sounding unnatural or otherwise unpleasant. For effective binaural hearing, precise neural spike timing of both ears is needed to encode ITD cues faithfully. Inhibition of responses to ITD cues is thought to be particularly affected by spiking behaviour, and by extension should also influence spatial hearing capabilities.

In this study, the effect of a weaker CI ear is simulated by assuming, that the spread of excitation is larger in one ear then in the other side. This would lead to excessive spiking both within and across channel, disrupting the precisely timed spiking on one side needed for binaural cue coding. In order to investigate the impact of having access to ITD cues virtual acoustics are used before and after bilateral syncronized CI vocoding to create conditions with only ILD cues or additionally with ITD cues.

Relative localisation and speech discrimination were measured using a dual task paradigm (Bizley et al., 2015). The participants heard two words in multi-talker babble noise, presented in a four-option closed-set paradigm, and spatially separated by 30 degrees. Initially, participants identified the words that they heard in order and, secondly, indicated if the second word was to the right or left of the first one. Spatial rendering (7 loudspeakers, -90° to 90°, in 30° steps) was implemented using virtual acoustics (Behind the ear-HRTFs), and 12 channel noise-vocoding was either applied before or after convolving with HRTFs to preserve ITD cues or not (ILD cues only). In addition, different spread of excitation asymmetries were simulated across ears (3.6 dB/mm vs. 7.2 dB/mm) or kept constant in both ears (3.6 dB/mm).

Preliminary results for normal hearing participants showed a 10-20% increase in relative localisation scores, when providing ITD cues in addition to ILD cues only. Spatial speech discrimination remains unaffected by providing ITD cues, which might be explained by the limited temporal fine structure inherent to vocoders (and CI sound processing). Asymmetries in spread of excitation lead to poorer localisation results, when the ear with the larger spread of excitation, was in the headshadow (e.g., poorer signal-to-noise ratio). The results suggest, that even under a binaural optimal situation (no interaural electrode mismatch, same pre-processing, and a healthy binaural system, which can make optimal use of all cues being presented) improved localisation abilities do not necessarily translate into improved spatial hearing.

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1441: CORRECTING FOR INTERAURAL PLACE-OF-STIMULATION MISMATCH IN BILATERAL COCHLEAR-IMPLANT USERS: SIMULATIONS ON HOW TO MAXIMIZE BINAURAL OUTCOMES

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Bilateral cochlear-implant (BI-CI) users perform significantly worse on binaural hearing tasks compared to normal-hearing individuals. This deficit is partially a result of interaural place-of-stimulation mismatch from asymmetric electrode array insertion depths. Current clinical practices in BI-CI programming do not account for interaural place mismatch, meaning that the standard frequency allocation table is not customized for electrode insertion depth for one ear or any difference between ears. The present study aimed to develop programming adjustment methods for reducing interaural place mismatch using computed-tomography (CT) scans, which contain precise electrode place information within the cochlea. The interaural place matching method prioritized precisely matching frequency information at each place of stimulation across individual interaural electrode pairs with an electrode-by-electrode adjustment. The interaural bandwidth matching method prioritized maintaining interaural bandwidth matching by aligning frequency information through an equal adjustment (shift) across the entire electrode array. We hypothesized that both methods would improve the binaural representation of the signals when compared to the standard clinical maps provided by the CI mapping software. We also hypothesized that the interaural place matching method would produce the best binaural representation.

A computational model was developed that measured the interaural cross-correlation of the envelope along the length of the cochlea. Each simulated cochlear place received input from multiple electrodes using a model of current spread. The binaural representation was simplified to a single value: the average interaural cross-correlation of the envelope across the electrodes, weighted by the energy of each place. The inputs to the model were information from the CT scans and the three mapping conditions (everyday clinical maps, interaural place matching maps, and interaural bandwidth matching maps) for 15 BI-CI users. The results showed an increase in interaural cross-correlation with the interaural bandwidth matching maps compared to the clinical maps, and unexpectedly showed a decrease when using the interaural place matching maps compared to the clinical maps.

The results of this study provide guidance for how to clinically approach BI-CI programming with an emphasis on improving binaural hearing. It was more important to correct for the overall shift but prioritize matching interaural bandwidths than to precisely match the place of stimulation and sacrifice the interaural bandwidth similarity. A clear next step will be to determine if the superiority of the interaural bandwidth matching approach improves behavioral performance relative to the everyday clinical maps.

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1445: EFFECT OF EXPERIMENTALLY INTRODUCED INTERAURAL PLACE-OF-STIMULATION MISMATCH ON SPEECH UNDERSTANDING IN BILATERAL COCHLEAR-IMPLANT LISTENERS

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Some bilateral cochlear-implant (BI-CI) users have interaural mismatch in place-of-stimulation. Such misalignment can arise from variation in electrode array positioning between the ears, due to insertion depth differences, for example. Interaural place-of-stimulation mismatch affects the perceptual fusion and centering of simple electrical stimuli in BI-CI listeners. The impact of interaural mismatch on speech understanding is unclear. If such mismatch is irrelevant during speech understanding, both-ear-performance should be no lower than the monaural better ear score.

The present study examined speech understanding in four BI-CI listeners as frequency alignment was manipulated. Each listener's clinical frequency allocations were used as the basis for 11-channel, continuous-interleaved-sampling (CIS) experimental maps in both ears, using every other electrode in Cochlear N6 processors. On each trial, listeners were presented with a single sentence in quiet spoken by a male talker. Frequency assignments in the poorer-ear map were shifted without frequency compression. Percent-words-correct scores for shifts equivalent to ±1.5, ±3 and ±4.5 mm, relative to a no-shift baseline condition, were compared. Control conditions with no shift, but where the same frequency channels were removed as in the case of the uncompressed shift, were also included.

Shifts greater than 3 mm reduced scores when listening with both ears as compared to the better ear alone for all three well-matched listeners, but not the one listener with a large insertion depth mismatch as indicated by CT scans. The control conditions that only removed frequency channels had minimal effect on performance relative to the no-shift baseline condition. Better monaural speech understanding in the poorer ear using clinical maps was associated with more interference from the shifted signal. Preliminary training data also indicate that listeners experiencing less benefit from their poorer ear more quickly adapted to the shifted signal, so as to improve their both-ear scores to the level of their better-ear scores. These data suggest that when mismatch is introduced there is either involuntary integration of information from the two ears, or perhaps a lack of fusion coupled with bilateral interference, except in cases where one ear is much more poorly performing than the other. These effects may interact with selective attention and spatial hearing abilities. Possible implications for programming and rehabilitation of BI-CIs will be discussed.

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1457: THE RELATIONSHIP BETWEEN SPATIAL RELEASE FROM MASKING AND LISTENING EFFORT AMONG COCHLEAR IMPLANT (CI) USERS WITH SINGLE-SIDED DEAFNESS (SSD)

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Spatial release from masking (SRM) refers to improvement in speech intelligibility when target and masker stimuli are spatially separated vs. co-located. SRM is a robust phenomenon in normal hearing (NH) listeners. In addition, subjective reports suggest that SRM is accompanied by reduced listening effort. We have been studying these effects in a unique group of patients with single-sided deafness (SSD) and NH in the opposite ear. Previous work has shown that cochlear implantation (CI) of the deaf ear in SSD patients can allow for an improvement in SRM, however, some listeners show the opposite - decreased SRM when listening bimodally (acoustic ear + CI ear) compared to listening with their acoustic ear alone. To date, there has been little research on the relationship between listening effort and spatial hearing benefits like SRM in the SSD-CI population. Further, the degree of asymmetry between the electric and acoustic inputs, quantified with speech intelligibility scores in quiet, has yet to be accounted for when interpreting the benefits of SRM. We hypothesized that SRM emerges as a function of symmetry in hearing across the ears, thus, SSD-CI listeners who exhibit small across-ear asymmetries would demonstrate greater SRM compared to listeners with large across-ear asymmetries. We also hypothesized that SSD-CI listeners who experienced improvements in SRM with their CI would demonstrate reduced listening effort.

Eight CI users with SSD were tested as part of a clinical trial. Speech intelligibility and pupil dilation (an objective measure of listening effort) were measured in quiet and in two noise speech-in-noise conditions: Co-located (target and masker at 0° azimuth) and spatially separated (target at 0° azimuth and maskers at +/- 90° azimuth). Three listening configurations were tested: acoustic ear alone, CI ear alone (acoustic ear occluded with an earplug and earmuff), and both ears (bimodal). Target speech recordings were IEEE sentences spoken by a male, and masker recordings were AzBio sentences spoken by two different males. Speech-in-noise conditions were tested at 0 dB signal-to-noise ratio.

Six of the eight listeners demonstrated more SRM in bimodal conditions than with the acoustic ear alone. Additionally, five of the eight listeners demonstrated less listening effort in the spatially separated relative to the co-located condition when comparing bimodal vs. the acoustic ear alone. Consistent with our first hypothesis, listeners with the smallest asymmetry exhibited the greatest SRM in the bimodal condition. Further, the listener who demonstrated the least SRM benefit and greatest amount of listening effort also had the greatest across-ear asymmetry. These promising findings suggests that the addition of a CI can benefit SSD patients, but that these benefits are associated with the extent of across-ear asymmetry.

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1461: THE EFFECT OF INTERAURAL MISMATCH IN THE ELECTRODE-TO-NEURAL INTERFACE ON INTERAURAL TIME DIFFERENCE SENSITIVITY FOR BILATERAL COCHLEAR IMPLANT RECIPIENTS

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Bilateral cochlear implant (BI-CI) recipients struggle to utilize interaural time differences (ITDs) in spatial-hearing tasks. Since ITD sensitivity is computed neurally in a typically functioning auditory system based on inputs that are interaurally matched with respect to place of stimulation, it may be affected by asymmetry in encoding. We investigated two possible facets of asymmetry related to the electrode-to-neural interface (i.e., the neural and non-neural factors affecting the efficacy with which an electrode activates a local neural population). First, there could be an asymmetry in the physical electrode placement across the ears, specifically the electrode scalar location and distances away from the modiolus. Second, there could be an asymmetry in the neural populations excited by the stimulating electrodes. Regions of poorer neural survival in CI recipients have been identified and indexed by the electrically evoked compound action potential (ECAP). It is not known to what extent asymmetry in neural survival and electrode placement (i.e., the electrode-to-neural interface) affect binaural-hearing outcomes. Therefore, we evaluated the effect of these two facets of asymmetry on ITD sensitivity.

Computed tomography (CT) scans were obtained to determine electrode distance from modiolus and scalar location (i.e., within scala tympani or scala vestibuli) for 10 BI-CI recipients. ECAP amplitude growth functions were also obtained to estimate neural survival. ITD thresholds were measured at single-electrode pairs using constant-amplitude low-rate electrical-pulse-train stimuli presented using direct stimulation. For the modiolar distance and ECAP measures, we computed ear difference parameters as well as parameters that captured the mean, minimum, and maximum values across ears. A linear mixed model and stepwise regression approach was used to find the predictors that best explained the variance in ITD sensitivity.

Initial analyses revealed that the best ITD thresholds occurred when ECAP responses were obtained in both ears for an electrode pair, and worse when obtained in only one or neither ear. Electrode pairs without ECAP responses were the most vulnerable to impaired ITD discrimination when electrodes were in different scala. We found a significant main effect for modiolar distance asymmetry ($p=0.010$), which was unexpectedly associated with improved ITD performance. Significant interactions occurred for minimum modiolar distance × modiolar distance asymmetry ($p=0.022$) as well as modiolar distance asymmetry × mean ECAP slope ($p<0.001$). The latter interaction indicated that asymmetry in the modiolar distance had a greater impact when the mean ECAP slope was relatively shallow (i.e., poorer neural preservation).

In summary, asymmetries in electrode-to-neural interface appears to impact ITD sensitivity in BI-CI recipients. Understanding and accounting for these types of asymmetries will help improve spatial-hearing outcomes in this population.

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1482: A COMPARISON OF BINAURAL CUES TRANSMITTED BY CLINICALLY AVAILABLE COCHLEAR-IMPLANT STIMULATION STRATEGIES

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Cochlear implants (CIs) effectively restore speech understanding in quiet in a majority of recipients. However, bilateral CI (BI-CI) listeners continue to perform poorly on spatial-hearing tasks (e.g., speech understanding in noise and sound localization) relative to acoustic-hearing listeners. Several factors, which can be broadly grouped into biological factors and device-related factors, have been suggested to constrain binaural performance. One suggestion, supported by modeling studies but relatively sparse empirical evidence, is that the signal processing performed by CIs degrades the fidelity of binaural cues transmitted to BI-CI users. This study investigated one aspect of CI signal processing – the stimulation strategy – and its effect on transmitted binaural cues. Binaural cues were measured via direct recordings of the electrical pulse trains generated by clinical sound processors in response to acoustic stimuli and compared between two clinically available stimulation strategies.

Two Cochlear Ltd. Nucleus 6 sound processors were placed on a binaural mannequin centered in a ring of loudspeakers in an anechoic chamber. Acoustic stimuli were presented from the loudspeakers and the resulting electrical pulse trains were recorded. Devices transmitted pulses to simulated electrode arrays with each active electrode connected to a recording interface. One set of recordings was made with the devices programmed with a stimulation strategy that preferentially allocates pulses to the highest-energy channels on a running basis (i.e., peak-picking) and another set with the devices programmed with a stimulation strategy that has no preferred channels and stimulates all active electrodes without interruption. It was hypothesized that the constantly stimulating strategy would transmit more replicable binaural cues across stimulus repetitions than the peak-picking strategy, as there is no channel selection process and therefore no risk of stimulating different subsets of electrodes across ears. Interaural level differences (ILDs) and envelope interaural time differences (ENV-ITDs) were extracted from the recordings and compared between stimulation strategies.

Recordings made with the peak-picking strategy demonstrated that the energy-based channel-selection process, which occurs independently at each device, can lead to substantially different subsets of electrodes being activated across devices at any given time, particularly for sounds presented away from the midline. Such asymmetry was shown to significantly impact binaural cue reliability, with variable ILDs and ENV-ITDs across stimulus repetitions for stationary sound sources. Ongoing comparisons with cues transmitted via the constantly stimulating strategy are expected to provide (1) insight on current BI-CI listener outcomes and (2) targets for modified stimulation strategies that may provide BI-CI listeners with more reliable cues for improved spatial hearing outcomes.

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1494: EXPLORING THE USE OF AUDITORY NERVE AND BRAINSTEM ELECTROPHYSIOLOGY TO IMPROVE SPATIAL HEARING IN CHILDREN USING BILATERAL COCHLEAR IMPLANTS.

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OBJECTIVE: To assess the use of electrophysiological measures to match stimulation parameters in children using bilateral cochlear implants (CIs) in order to improve spatial hearing.

BACKGROUND: When bilateral CIs are provided to children who are deaf it allows them to gain some access to spatial hearing. Clinical protocols that map CIs emphasize audibility in each device separately, but can set up "mismatched" bilateral input which deteriorates access to binaural cues and results in impaired sound localization. We have previously found that levels at which children perceive bilateral CI input as “balanced” (neither weighted to left or right sides) can be predicted by similar amplitudes of unilateral auditory activity measured by the electrically evoked compound action potential of the auditory nerve (ECAP), the electrically evoked auditory brainstem response (EABR), and also by increases in binaural inhibition as measured by the Binaural Difference response (Sum of unilateral EABR amplitude - bilateral EABR amplitude). A more efficient method of predicting balanced bilateral CI levels may be to focus on changes in the amplitude of the bilaterally evoked EABR. We hypothesize that: 1) levels that evoke similar ECAP and EABR amplitudes from each side also elicit maximum binaural inhibition measured by smaller bilateral EABR amplitudes, and 2) decreases in bilateral EABR amplitude correspond to balanced bilateral input.

METHODS: Pilot testing has been completed in 6 children (mean age(SD) = 13.82(5.92) years) who have used bilateral CIs for mean(SD) = 5.56(6.12) years at the time of testing. Matched inter-implant level (ILD=0) was predicted by matched amplitudes of ECAPs recorded by pairs of electrodes at along the CI array (20:20, 9:9, 3:3) at the time of bilateral implantation. Unilateral EABRs were recorded at the levels producing ILD=0 and bilateral EABRs were recorded at 5 ILD conditions (0, +/-4, +/-8 CU, where + is weighted to right CI and – is weighted to left CI). Behavioural responses to these bilateral stimuli will be measured in a lateralization task.

RESULTS: Preliminary analyses suggest consistency between differences in ECAP amplitude and differences in unilateral EABR amplitudes across the ILD conditions. Relationships between the unilateral responses and the bilateral EABR amplitude are not clear. Added behavioural data will be used to determine whether balanced bilateral input can be predicted by the bilateral EABR.

CONCLUSIONS: It is not yet clear whether bilateral EABR has better potential than unilateral auditory nerve and brainstem responses to provide an objective measure for matching bilateral CI levels.

1496: EFFECTS OF COCHLEAR IMPLANTATION ON EXPLORATION OF SOUNDS IN SPACE IN CHILDREN WITH ASYMMETRIC HEARING LOSS INCLUDING SINGLE SIDED DEAFNESS

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Spatial hearing is important for listening to one sound in a background of noise and relies on the integration of interaural timing and level cues. Access to these binaural cues decrease as hearing loss becomes more asymmetric between the two ears, potentially requiring compensatory head and eye movements to visually explore locations of sound sources. The aims of the present study were to: 1) identify the extent to which children with asymmetric hearing including single-sided deafness, accurately localize stationary and moving sound when able to freely move their head and eyes and 2) to measure the effects of restoring hearing with a cochlear implant (CI) to reduce the hearing asymmetry on accuracy of spatial exploration.

Accuracy of locating a stationary sound at an initial location (L1) and of locating sound that moved from L1 to a second location (L2) was measured in 9 children with single side deafness (SSD) who received a CI (SSD-CI) (MAge = 13.1 ± 4.26 SD), 4 children using a CI in one ear and a hearing aid in the other ear (bimodal) (MAge = 12.2 ± 3.95 SD) and 14 adolescents/young adults with normal hearing (NH) defined as having pure tone averages no greater than 20 dB HL in both ears (MAge = 22.8 ± 13.0 SD). A speaker fixed to the end of an L-shaped moving arm presented band-pass filtered white-noise at a distance of approximately 1-m from the listener along a pseudorandom range within a 120° arc in the frontal azimuthal/horizontal plane. Wearable eye-tracking glasses and a motion tracker measured unrestricted eye movements and head movements, respectively, in real-time. For each participant, 30 trials were completed in bilateral and unilateral conditions: CI on vs CI off in SSD-CI and bimodal users and both ears open vs unilateral/right ear plugging (foam plug and ear-muff) in the NH cohort.

Localization errors of stationary sound at L1 were higher in SSD-CI and bimodal groups compared to NH peers ($F(2, 21.5) = 10.1$, $p < 0.001$) and there was a significant group x listening condition interaction [$F(2, 20.7) = 6.7$, $p < 0.01$]; error increased in the unilateral (earplug) than bilateral condition in NH [Estimate(SE) = 20.44(2.98), $p < 0.001$] whereas it was unchanged in the unilateral condition (CI off) compared to bilateral (CI on) in both SSD-CI [Estimate(SE) = 2.46(3.94), $p = 0.54$] and bimodal groups (Estimate(SE)= 10.94(6.30), $p = 0.09$). Localization of sound that moved to L2 showed the same degree of error as for L1 in all 3 groups [$F(1, 65) = 0.0$, $p = 0.99$] with similar statistical findings of group [$F(2, 22.2) = 11.9$, $p < 0.001$] and group x condition interaction [$F(2, 21.7) = 7.3$, $p < 0.01$]. Further analyses assessed the perception of movement direction (left or right) using binomial logistic regression across trials for each participant. Analyses revealed steep slopes in children with NH, revealing high accuracy for motion direction and significantly reduced slopes in the SSD-CI and bimodal groups [$F(2, 45) = 62.0$, $p < 0.001$]. A group x condition interaction [$F(2, 45) = 30.1$, $p < 0.001$] revealed significantly decreased slopes in unilateral (plugged) versus bilateral condition in the NH group [Estimate(SE) = 0.89(0.07), $p < 0.001$] and no significant differences in slopes in unilateral (CI off) versus bilateral condition (CI on) in the SSD-CI [Estimate(SE) = 0.001(0.09), $p = 0.98$] and bimodal groups [Estimate(SE) = 0.106(0.15), $p = 0.49$].

Preliminary analyses suggest that losing bilateral hearing by unilateral ear plugging is detrimental for localizing stationary and moving sound in NH individuals and results in disproportionate movement of the head to favour the better hearing ear. Sound localization is far less accurate in children with asymmetric hearing, including SSD-CI, compared to NH controls and questions about potential improvements with CI use remain.

1497: PERCEPTION OF SOUND FOR A BILATERAL INTERLACED CI CODING PARADIGM

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Present day CI coding strategies impose limits on the amount of acoustic spectral information conveyed electrically to the available nerve fibers. The Advanced Combination Encoder (ACE) algorithm, for example, restricts the number of available active electrodes per stimulation frame, thereby limiting its information transmission ability. The conventional Continuous Interleaved Sampling (CIS) coding strategy transmits signals on all available electrodes sequentially, but cannot completely avoid stimulus interactions of the processed signal at the neuronal interface. Furthermore, ACE and CIS are unilateral signal processing approaches and provide no synchronization or communication between bilateral processors.

To counteract these restrictions, a novel coding approach was developed and is currently evaluated in human subjects. This new bilateral interlaced paradigm (InterlACE) attempts to take advantage of the brain's ability to fuse signals into a single perceptual sound image, selecting channels in such a way as to increase the active spectral components presented, while reducing the channel interaction. More specifically, each stimulation frame activates only every second electrode, alternating between odd and even electrodes in consecutive frames. This results in an interlaced coding paradigm presenting spectral components in an alternating manner both spatially and temporally. Potentially, the spectrotemporal characteristics of the input signal will be more effectively reproduced with diminished crosstalk between adjacent channels, which may lead to greater spectral information transmission. The interlaced coding method is based on ACE and implemented in MATLAB based on Cochlear's Nucleus Implant Communicator (NIC) library. The interlacing process can be extended to a bilateral version to gain further benefits of the channel alternation by effectively distributing active channels in both ears.

A current experimental study with 10 experienced bilaterally implanted adult CI subjects explores simultaneous multichannel masking, sentence recognition in noise, spectral resolution, pitch discrimination and sound localization in virtual acoustic environments. InterlACE and the reference ACE coding strategy are evaluated in randomized trials in the laboratory.

Preliminary outcomes indicate similar performance with InterlACE unilateral and bilateral coding variations compared to ACE. A trend for improved sound perception in specific conditions was observed for pitch discrimination and localization in noisy environments. Results of the ongoing evaluation will be presented at the conference.

1362: CLINICAL DECISIONS IN EAS CANDIDATES AFFECT ELECTRIC SPECTRAL REPRESENTATION

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Background: The management of cochlear implant (CI) candidates with residual acoustic hearing introduces unique considerations. The first is length of the electrode used for implantation. Shorter electrodes may improve preservation low-frequency residual hearing. However, if the residual hearing is not preserved, it is expected that standard-length electrode arrays will provide better outcomes with electric-only stimulation. The second consideration is that of the low-frequency cutoff for the electric map in an electroacoustic stimulation (EAS) configuration. Typically, the low-frequency cutoff is selected based on the audiogram to divide the auditory information into low-frequency information presented acoustically and mid-to-high frequency information presented electrically.

While not typically considered in clinical management, both manipulations are expected to have an effect on the spectral representation of the electric signal. For a given frequency allocation, longer electrodes represent the frequencies across a greater cochlear extent, increasing the spacing in the cochlea for harmonic and spectral information. For a fixed electrode length, raising the low-frequency cutoff has a similar effect. That is, increasing the low-frequency cutoff results in a reduction in the frequency range represented by a fixed cochlear extent. This results in an increased physical separation along the cochlea for harmonic and spectral information. Therefore the choice of electrode length and low-frequency cutoff will have a significant effects on spectral representation in the cochlea.

In the following study, the effects of electrode length and low-frequency cutoff on spectral representation is predicted with a simple model based on cochlear geometry. Psychophysical data with two different cut-offs and simulated electrode lengths are collected to verify the model predictions.

Methods: Models of spectral representation within the cochlea were derived from estimates of electrode location for 270° and 360° degree insertions using two different low-frequency cut-offs (250 and 500 Hz) for the frequency allocation. In this configuration, it was predicted that both increased length and low-frequency cutoff would improve spectral representation, but the effect of increasing the electrode length would be greater. These models were tested with standard-length Cochlear electrode users. Spectral resolution was measured with two commonly used broadband tests (SMRT and QSMD). Two simulated array lengths (short, 11 basal electrodes, or standard, 11 even electrodes) and two low-frequency cutoffs (188Hz or 438 Hz) were used. All combinations were tested acutely.

Results: Consistent with the model, increasing electrode length and raising the low-frequency electric cutoff both improved performance on both the SMRT and QSMD tasks. For the particular parameters chosen, a greater improvement for spectral resolution was seen for increasing electrode length compared to decreasing low-frequency cutoff. Combining both manipulations resulted in the largest improvement.

Conclusions: Improvements in spectral resolution caused by increasing electrode length and/or low-frequency cutoff may improve the electric representation. This may be very important as measures of spectral resolution are correlated with speech perception outcomes. These factors should be considered when choosing electrodes and programming parameters for CI users with residual hearing.

1437: DECODING SELECTIVE ATTENTION FROM SINGLE-TRIAL EEG DATA IN COCHLEAR IMPLANT USERS WITH IPSILATERAL RESIDUAL HEARING

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Introduction: Cochlear implant (CI) users with ipsilateral residual hearing receive electric and acoustic stimulation (EAS). The combination of both stimulation modalities results in significant benefits in terms of speech understanding when listening to EAS in comparison to electric stimulation (ES). This benefit is typically measured through behavioral speech understanding tests. These tests are time consuming, require sufficient experience by the audiologist and are not possible to measure in very young children or subjects with missing behavioral response. Recently, it has been suggested that neural tracking to speech from electroencephalography (EEG) can predict speech understanding in normal hearing listeners. Moreover, it has been shown that it is possible to decode selective attention in CI users, even if the continuous CI electrical artifact may obscure the neural responses in the EEG. The main goal of this work is to investigate selective attention decoding in EAS subjects listening to ES only, acoustic stimulation (AS) only and to combined EAS. The hypothesis is that selective attention decoding will be larger with EAS than with ES or AS and that this difference may correlate with the speech understanding benefit provided by EAS in comparison to ES or AS.

Methods: Seven EAS subjects participated in the study. First, behavioral speech understanding performance was measured at ES, AS and EAS modes. The speech material consisted of target HSM sentences with a competing talker of opposite gender. Second, cortical auditory evoked potentials (CAEPS) were recorded by presenting broadband clicks at ES, AS and EAS listening modes. Third, selective attention (SA) was measured through EEG by monaural presentation of two concurrent speech streams at EAS, ES and AS. During SA task, subjects were asked to attend to one of the two concurrent speech streams. Stimuli were provided through the Presentation software (Neurobehavioral Systems, California) and EEG was recorded using a high-density EEG cap with 96 electrodes (Easycap, Germany) linked to the recording system BrainAmp (Brain Products, Germany). SA was decoded using a backward model to reconstruct the envelope of the attended speech stream from EEG. SA performance was estimated based on the correlation coefficient between the attended or unattended speech streams and the reconstructed one. In order to reduce physiological and electrical artefacts 2-step ICA methodology was applied to the EEG signals.

Results: The N1-P2 complex of CAEPs response elicited by EAS was larger than the response elicited by ES or AS. A significant effect of listening mode (ES, AS or EAS) on the correlation coefficient difference between the attended and unattended speech stream was observed. Moreover, SA decoding with EAS obtained higher values than with ES or AS, showing a SA EAS benefit. However, no significant correlation between the SA benefit and the speech understanding benefit was found, although the dataset was small.

Conclusions: In summary, this work shows that 1) it is possible to decode selective attention in CI users even if continuous artifact is present; 2) SA at EAS is larger than with ES or AS demonstrating that the electrical artifact does not obscure the neural signals in the EEG.

1449: CONTRIBUTION OF LOW-FREQUENCY INFORMATION TO THE SPEECH PERCEPTION OF COCHLEAR IMPLANT USERS WITH IPSILATERAL RESIDUAL HEARING CONVEYED THROUGH ACOUSTIC OR PHANTOM STIMULATION

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Cochlear implantation allows the preservation of low-frequency residual hearing during and after implantation. Most of today’s cochlear implant (CI) speech processors include an acoustic component (hearing aid) to provide low-frequency acoustic stimulation in combination with electric stimulation. The benefit of combined electric-acoustic stimulation (EAS) was the inspiration for the development of stimulation modes that convey low-frequency information electrically. The so-called phantom stimulation (PS) uses the two most apical electrodes in a partial bipolar configuration to shape the electrical field in the cochlea. Thereby, it is possible to elicit a sound sensation that is lower in pitch than the sensation evoked by monopolar stimulation with the most apical physical electrode.

The aim of this study was to evaluate the contribution of low-frequency information conveyed through acoustic or phantom stimulation to the speech perception of cochlear implant users with ipsilateral residual hearing. Speech reception thresholds (SRT) were measured and compared to each other with electric stimulation alone, with electric-acoustic stimulation and with electric stimulation combined with phantom stimulation. Additionally, the effect of low-frequency information conveyed via simultaneous phantom and acoustic stimulation was investigated.

The results show a significant improvement in SRT through the presentation of low-frequency information using either acoustic or phantom stimulation. No significant differences between the SRTs were observed if low-frequency information was conveyed through acoustic or phantom stimulation. However, the lack of this significant effect may be explained by the low number of subjects tested as two subjects were not able to perform the speech understanding task without acoustic stimulation. If phantom stimulation and acoustic stimulation simultaneously conveyed spectrally overlapping low-frequency information, SRTs were worsened compared to the SRTs obtained from EAS.

The results suggest that phantom stimulation could be an alternative option for EAS-users if the use of acoustic stimulation is not possible. Furthermore, the simultaneous presentation of low-frequency information by two modalities should be avoided.

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1459: F0 DISCRIMINATION COMPARED TO SENTENCE AND EMOTION RECOGNITION IN YOUNG AND ELDERLY NORMAL HEARING ADULTS USING VOCODED SPEECH

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Background: Temporal-envelope based voice-pitch coding is important for listeners with cochlear implants (CIs) because spectral resolution does not provide sufficient information for a spectrally based voice-pitch cue. More specifically, the encoding of fundamental frequency (F0) information is critical to communicating for these individuals in complex environments. Voiced speech can be approximated by a harmonic complex, with the perceived pitch of talkers' voices roughly corresponding to the F0 of the harmonic complex. Differences in F0 discrimination between young and elderly normal hearing individuals have been shown, with elderly individuals performing more poorly. Additionally, differences have been observed between young and elderly individuals listening through CI vocoders with different numbers of spectral channels. As well, sex of the talker has had an effect on discrimination of F0. With these previous findings, little is still known about how using temporal-envelope based voice-pitch coding compares to real life listening situations.

Objectives: The objectives of this study are to compare results between younger and elderly individuals with normal hearing (at least up to 2000 Hz) and measure noise-vocoded listening by:
1) Measuring F0 discrimination using F0 of 100 and 200 Hz & 8 and 24 channel vocoders, with a 2000 and 4000 Hz cut-off
2) Measuring 8-channel sentence recognition in quiet and in +5 SNR babble using male and female talkers
3) Measuring emotion identification using male and female talkers with the original stimuli and 8-channel vocoder

Methods: Seventeen participants (11 young; 19-26 years of age) and (6 elderly; 65 – 78 years of age) completed four hours of testing divided into two separate days. Each day consisted of three different tests that were randomly ordered. The three tests consisted of a 3-alternative forced choice (3AFC) task, emotion identification, and IEEE sentence recognition with different-sex talkers and listening conditions.

Results and Conclusions: In the 3 AFC task, results showed a significant effect for F0 with sex of talker and for age in the 3AFC task. In the IEEE task, there was a significant effect for sex of talker. For the emotion recognition task, participants performed better with the female talker and original (unvocoded) stimuli, and there was an age effect. The aging and sex of talker effects in the 3AFC task may be related to the results found in the everyday listening tasks of emotion recognition and listening to speech in quiet and noise.

1513: SPEECH PERCEPTION AND LISTENING EFFORT IN CI SUBJECTS WITH ELECTRIC-ACOUSTIC STIMULATION

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Introduction: The use of electric-acoustic stimulation (EAS) is an established treatment in patients with partial deafness and residual hearing in the low frequencies. Improved speech perception in noise and better sound quality (especially in enjoyment of music) have been shown in several studies compared to users of cochlear implants (CIs) with only electric stimulation. The aim of the present study was to assess speech perception and listening effort in EAS subjects in demanding listening conditions and in reverberation.

Methods: 8 subjects with bilateral CIs, 8 bimodal EAS subjects, 8 bilateral EAS subjects and a normal hearing group (NH, n=17) took part in the study. Speech reception thresholds (SRTs) in situations with spatially separated and temporally modulated noise sources were assessed with the German matrix test in free-field and in reverberation. A sound reproduction setup comprising 128 loudspeakers was used for simulation of room acoustics in a classroom of typical size. Furthermore, listening effort (LE) was estimated using an adaptive category scaling procedure (ACALES). EAS users were tested with (1) default EAS fitting, (2) electric only and (3) an electric full-frequency MAP.

Results: Significant deterioration of mean SRTs in reverberation were found for all subject groups compared to free-field conditions (NH: 10 dB, CI/EAS users: 4-6 dB). EAS users had no better SRTs in reverberation compared to the bilateral CI group. EAS groups showed better SRTs in modulated noise than bilateral CI users (SRT difference: 4-6 dB). However, the SRT difference to normal hearing subjects was still up to 20 dB. EAS users achieved best SRTs with their clinical EAS fitting and worst SRTs with the electric full-frequency fitting. The benefit of EAS use was highest in modulated noise (mean SRT difference EAS vs. electric full-frequency: 2.5 dB).
Mean LE in EAS groups was significantly lower than in the bilateral CI group (e.g. for modulated noises in reverberation: 4 categories). EAS users had lowest LE with their clinical EAS fitting and highest with the electric full-frequency fitting (up to 2 categories difference).

Conclusion: The beneficial “EAS effect” compared to bilateral electric listening was shown in the measurements of speech perception and listening effort in complex noise conditions.

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1507: BILATERAL SPEECH PERCEPTION IS DISRUPTED WHEN ONE OR TWO EARS PROVIDE DEGRADED SPEECH

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Listeners with bilateral cochlear implants (BiCIs) and simulations in normal-hearing (NH) struggle ignoring speech from a clearer ear. This effect is especially pronounced when both ears exhibit degraded speech understanding. One explanation for these findings is poor allocation of attention to degraded signals in general. However, a wider range of perceptual experiments (e.g., pitch fusion, spatial fusion) and anecdotal reports suggest that listeners with BiCIs have a tendency to maladaptively integrate sounds across the two ears. Thus, poorer speech understanding when one or both ears are degraded could be explained by maladaptive integration of speech across the ears.

The goal of the present experiment was to investigate the speech perception of words presented across the ears where one ear provides a degraded signal (i.e., interaural asymmetry), or both ears provide degraded signals. Using an existing “phonological fusion” paradigm [Cutting, 1976, Psychol Rev, 83(2), 114-140], we investigated which word(s) listeners heard in three different configurations: (1) same word in both ears, (2) two rhyming words to different ears beginning with different stop (/p/, /b/, or /g/) and liquid consonants (/l/ or /r/), and (3) two non-rhyming words to different ears. This paradigm was designed such that rhyming words could be “fused” together into another word in English (e.g., “pay” + “lay” = “play”). The task was closed-set and newly recorded stimuli from one male were used.

Younger listeners with NH were presented with vocoded speech via circumaural headphones. Vocoding was completed by filtering stimuli into eight or sixteen frequency bands between 150-8000 Hz using noise carriers. Speech was degraded and interaural asymmetry was simulated by compressing the envelope of speech in one ear to a given percentage (e.g., 40, 60, 80, or 100%) of its original dynamic range in listeners with NH. The overall level remained at 65 dB(A) in all cases. Preliminary data from listeners with BiCIs were collected via direct connection to the auxiliary port of their device or circumaural headphones with their clinical MAPs. Speech understanding differed between listeners with BiCIs and the ear being tested, suggesting differences in the fidelity of speech between listeners and ears.

When rhyming words were used, listeners in both groups were more likely to report hearing one word compared to non-rhyming words, especially when one or both ears were degraded. This suggests that listeners integrated speech information across ears and that integration increased when speech was degraded. Additionally, listeners were more likely to report a word that did not correspond to either ear when one or both ears were degraded, suggesting that degraded speech interfered with understanding. Together, these findings indicate that degraded speech can disrupt speech perception across ears. This is at least one mechanism in addition to attention that may contribute to poorer speech understanding when there are differences in clarity, or low clarity overall, between the ears of listeners with BiCIs.

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Music and Pitch – Featured Talks and Posters

Invited Recorded Talk:

1527: USING ATONAL MUSIC TO UNDERSTAND MUSICAL EXPERIENCE OF CI USERS.

Jeremy Marozeau
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Despite having a weak perception of pitch, harmony, and timbre, many CI users are still actively engaged in musical activities. To enjoy music, they must focus their attention or put different weights on additional musical cues such as rhythm, tempo, or dynamics. A better understanding of the listening experience of CI users could help us to design efficient musical programs. Despite many attempts to simulate the perception of music through a CI, no clear conclusion can be drawn other than a large variability in described sensation among CI users. When people with normal hearing, NH, listen to speech processed through some vocoders, their speech understanding scores can be similar to CI users listening to the same stimuli. However, these models generally fail to recreate the sound quality experienced by a CI user. We proposed to use atonal music to simulate the musical experience (not sound quality) of CI users. During this presentation, I will review some of our previous experiments that used such stimuli.

In a first experiment (Spangmose et al. 2019, Frontiers of Neuroscience), we have asked CI users to rate in real-time the perceived musical tension of a piano sonata of Mozart played by a musician on a digital keyboard. We showed that we could reproduce a similar tension profile with NHL rating a modified version of the piece in which all the notes were randomized. This result suggested that CI users relied mostly on the dynamic changes of the music, rather than tonal harmony, to experience tension and release in music.

In a second experiment, we have asked CI users to rate the musical emotion (happy-sad) and preference (like-dislike) of piano pieces (Vannson et al., 2015, Trends in Hearing). Surprisingly, the CI users correctly identified the music emotion and showed a clear preference for happy pieces. On the other hand, results with NHL on similar stimuli revealed no clear preference. They enjoyed as much sad and happy pieces. In a follow-up study, we asked NHL to rate a version of the stimulus played on the congas (each note played on the left hand was replace by a strike on the low conga, and each note played on the right hand on high congas). Results showed that NHL preferred the happy pieces from the sad ones when the tonal cues were removed.

In a third experiment, we asked CI and NHL listeners to rate the musicality of a classical piano piece and its modified version in which each note was reassigned to the closest note on a pentatonic scale. This latter transformation allows us to create a musical piece that is always consonant. We could observe a decrease in the rating of the modified version only for NHL. This last result shows that CI users do not perceive complex harmonical relationships, and purely consonant or dissonant music might better represent their musical experience.

Based on these studies, we argue that CI users might still enjoy music because they can rely on other non-tonal cues. As some of us can enjoy contemporary music, Schoenberg could become the new vocoder.

Featured Recorded Talk:

1313: THE VOICE QUALITY IN COCHLEAR IMPLANT USERS

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Objectives:
Pitch is one of the attributes that described the quality of voiced speech. Defining this voice parameter has an important role in diagnosis of voice disorders. Cochlear implant users have difficulties in pitch discrimination because of distortion of F0 and harmonic structures. Differences in the frequency locations in cochlear implant may cause a conflict between the signal is presented and what is heard by these users. These users often hear the voice with a higher pitch. In this study, we aimed to investigate voice quality by pitch parameter in cochlear implant users.

Method:
Thirty postlingually deaf adults with bilateral cochlear implants were in this study. Three experimental conditions were created: both off devices, both on (bilateral), and using only one device (unilateral). Data were collected for three vocal tasks that were sustained vocalization, reading “The Rainbow Passage”, and singing “Happy Birthday”. The median and mode of Pitch Strength and Smooth Cepstral Peak Prominence were calculated.

Results:
The result suggests that PS and CPPS are higher in the off condition and the differences with the other two conditions were significant.

Conclusion:
This study shows that because the mismatch between frequency of presented signal and what has been processed in their devices and the difference between two ears, CI users push their voices toward lower frequencies. In this situation, auditory feedback is a tricky tool making them think their voice pitch is not correct. When their CIs are off and they don’t have access to the feedback, users don’t try to change the pitch of their voice. Therefore, the quality will be sensed better. This study supports the idea that CI users might have voice disorders.

Featured Recorded Talk:

1405: COCHLEAR IMPLANT USERS' PERCEPTION OF MUSICAL TIMBRE DIMENSION

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Timbre perception is fundamental to music enjoyment. Previous cochlear implant (CI) studies investigated musical instrument identification and timbre perception using dissimilarity ratings, but to improve timbre perception for CI users, it is necessary to gain a deeper understanding of the extent to which timbre information contained in the acoustic stimulus is received by the CI listener. The present study investigated timbre perception by measuring just-noticeable differences of a set of representative acoustic properties that underlie timbre perception and performing a fuzzy feature information transmission analysis (F-FITA).

Two spectral dimensions, brightness and irregularity, and two temporal dimensions, attack and decay, were identified in literature as core timbre dimensions. The acoustic properties related to these timbre dimensions were used in a synthesis model to create a set of nine synthetic instrument tones. The latter allows for the independent variation of the acoustic properties across the four timbre dimensions. Synthetic tones were used in a set of two-alternative forced-choice experiments to measure just-noticeable differences (jnds) for normal hearing (NH) individuals and CI users for each of the timbre dimensions.

The jnds were used to generate a probability density function for each instrument in four-dimensional timbre space, from where an instrument confusion matrix was then predicted. The percentage of information received by each participant in the two listener groups was calculated with an F-FITA using these predicted confusion matrices.

Overall, between 87% and 100% of timbre dimension information was received by NH listeners, while timbre dimension information transfer to CI users was highly person-dependent, ranging from 8% to 92%. In comparison to NH results, brightness was the dimension most poorly perceived by CI users, while the highest information transmission was for spectral irregularity. Surprisingly, some CI users approached the performance of NH listeners in some of the conditions.

A core objective was to gain an understanding of what underlies timbre perception. Results were analysed with the aid of a model to determine whether CI users attended to musical timbre variations, or to signal variations. This analysis showed that CI listeners could make use of musical timbre in at least some of the conditions. The study produced some insights into the way in which CI speech processors influence timbre perception.

1312: A VERSATILE DEEP-LEARNING-BASED MUSIC PREPROCESSING SCHEME FOR COCHLEAR IMPLANT USERS

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Several studies have shown that CI listeners prefer music genres like country or pop music over complex genres like classical music and pieces with a small number of voices or instruments over bigger line-ups. An emphasis on the melody and on rhythmic elements and an attenuation of the accompaniment promote their access to music.

In this contribution we present a versatile source mixture model (SMM) that combines deep-learning based music source separation (DNN-SS) with harmonic/percussive source separation (HPSS). While both DNN-SS and HPSS have been applied in music preprocessing methods for CI listeners before, the proposed SMM allows individual mixtures of the harmonic and percussive portions of four sources, i.e. (sung) melody, drums, bass, and other accompaniment. For instance, an emphasis on the melody can be achieved while the rhythmic information from drums and bass is maintained and the harmonic and percussive parts of the remaining accompaniment are attenuated. Hence, a remix with a sparser spectral representation can be obtained which facilitates the transmission via the coarse electrical-neural interface of the cochlear implant. To this end, two different network architectures, a U-Net (Hennequin et al. (2020), JOSS, 5(50), 2154) and a MaD TwinNet (Drossos et al. (2018), IWAENC 2018, 421-425), were trained to remix the harmonic and percussive portions of each the four sources with particular weights using multi-track recordings taken from the MUSDB18 corpus (Rafii et al., (2017), zenodo.1117372).

An evaluation of the proposed SMM and both network types was performed with 13 normal-hearing listeners in conjunction with a CI simulation (Grange et al. (2017), JASA, 142(5) EL484-EL489). Eight 12-seconds long music extracts were selected based on a full-factorial experimental design with three factors and two levels per factor: “Singer gender” (male/female), “background vocals” (yes/no), and “music complexity” (low/high). Each extract contained vocals, bass, drums and other accompaniments. The experiment was conducted following a MUSHRA-type design with an open reference, a hidden reference, an anchor, and two different remix models for each network (i.e. six conditions to compare). We chose the unprocessed signal as the reference and the percussive signal component of the reference as the anchor. The ratings were measured on a category comparison rating (CCR) scale since it allows to indicate an improved, a degraded, or a similar signal quality.

A statistical analysis shows that the preservation of all source-wise percussive parts and the harmonic parts of vocals (and optionally drums) is rated significantly better than the reference and the anchor. Moreover, relative to the open reference and across all mixture models, complex music pieces were rated significantly higher after processing than less complex music pieces, whereas the average rating for the hidden reference was even slightly lower for complex music.

In conclusion, the proposed remixing technique offers a versatile music preprocessing framework allowing to adjust individual gains for the percussive and harmonic components of each source in a music piece. Remixing models which preserve the percussive components of all sources and the harmonic components of the main singing voice and drums have achieved the best performance and unfold their highest potential for complex music pieces.

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1314: INSERTION DEPTH AND VOCAL PITCH DIFFERENCES FOR COCHLEAR IMPLANT USERS

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Objectives: Adults with bilateral cochlear implants (CIs) produce different vocal pitches (F0) when producing sustained vowels and singing “Happy Birthday” depending on whether they are using their left or right CI. Electrode insertion depth variability across ears may be one cause of this difference, given that differences in stimulation location cause a shift in pitch perception in single-channel studies. Because of the tight link between perception and production, such shifts in perceived pitch may lead to productions that differ in F0 as well. In this study, we aimed to investigate the role of insertion depth on this production of different vocal pitches when using the right versus the left CI.

Design: Eleven bilateral CI users participated in this study. In order to mimic differences in insertion depth, four electrodes were deactivated, either at the apical or the basal end of the array. Data were collected for two vocal tasks: producing a sustained vowel and singing “Happy Birthday.”

Results: The results indicated that participants did not change their vocal pitches in response to different simulated insertion depths. The difference between apical and basal conditions was not significant.

Conclusions: The results of this study suggest that insertion depth differences across ears cannot explain the shift in vocal pitch that occurs when bilateral CI users produce sustained vowels and sing “Happy Birthday” when using one CI versus the other.

1356: CUE-WEIGHTING FOR EMOTIONAL PROSODY IDENTIFICATION BY CI USERS: A COMPARISON OF SOUNDBOOTH, QUIET ROOM AND REMOTE/IN-HOME TESTING METHODS

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Cochlear implant patients have impaired identification of emotional prosody, primarily due to poorer perception of complex harmonic pitch compared to normally hearing listeners. Secondary cues such as loudness and duration, however, also convey important emotion information. We investigated CI patients' reliance on voice pitch contour, duration, and intensity cues in a happy/sad emotion identification task in which each of the cues were manipulated orthogonally in the stimulus samples. The original sentence "Time to go", recorded by an adult female talker in a happy and a sad way, was manipulated to have a total of five F0 contours ranging from happy to sad. Each of these versions of the sentence was then manipulated to have durations ranging from short (expected to be perceived more as happy) to long (expected to be perceived more as sad) and intensities ranging from louder (expected to be perceived more as happy) and softer (expected to be perceived more as sad). The listener heard these samples individually and indicated whether they sounded happy or sad in a single-interval, 2-alternative forced choice task. The data were then analyzed in regression analyses and coefficients were derived to indicate listeners' reliance on each of the three cues – F0 contour, duration, intensity. The experiments were conducted in three conditions – in the soundbooth, in a quiet room with a standard laptop, and remotely in the participant's home, with varying equipment and acoustic conditions. Participants were CI users and NH listeners; the NH listeners also heard noise-vocoded versions. Preliminary analyses indicate that CI users show strong intersubject variation in their use of the F0 contour cue and the duration cue. The NH listeners showed strong reliance on F0 and duration cues, with the reliance on F0 cues reducing as the signal became more strongly degraded. Intensity cues did not play a role in these studies, likely because F0 and duration cues strongly contrasted the two emotions. Preliminary analyses indicate that changing the site and equipment for tests increased the intersubject variability of the derived coefficients. Further data on effects of participants' age on cue-reliance are being presently collected and will be presented.

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1357: EFFECT OF TEMPORAL CUES ON PITCH DISCRIMINATION AND PITCH-TIMBRE CONFUSIONS WITH SYNTHETIC VOWELS IN COCHLEAR IMPLANT USERS

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Introduction: Pitch and timbre perception are problematic for cochlear implant (CI) users. Moreover, concurrent changes in pitch and timbre cues can cause perceptual confusion. These perceptual deficiencies and pitch-timbre confusions may be due in part to representation of the temporal envelope by current CI sound-processing strategies. Most current strategies use amplitude-modulated (AM) stimulation, but variable-rate (VR) stimulation might provide better pitch discrimination and resolved pitch-timbre confusions.

Objective: To compare amplitude-modulated and variable-rate stimulation and their effects on pitch discrimination and pitch-timbre confusions in CI users.

Methods: Multi-electrode synthetic vowels were used as stimuli in a 2-interval, 2-alternative, forced-choice procedure. Adult CI users were asked to identify which of the two vowel stimuli was higher in pitch. Testing was conducted under two conditions: a constant-vowel condition and a variable-vowel condition. In the constant-vowel condition, the two vowel stimuli were the same with identical formant frequencies. In the variable vowel condition, the vowel stimuli were not identical with different formant frequencies. Each condition was tested with the fundamental frequencies of the synthetic vowel stimuli encoded by either AM or VR stimulation. Vowels encoded by AM stimulation conveyed pitch with a constant-rate pulse train with a modulation frequency equal to the fundamental frequency. Vowels encoded by VR stimulation conveyed pitch using a pulse train with a firing rate equal to the fundamental frequency. For both AM and VR stimulation, the formant frequencies were encoded spectrally along the electrode array. Pitch discrimination was assessed around a fundamental frequency of 220 Hz for the two stimulation types (AM and VR) for both the constant- and variable-vowel conditions.

Results: Preliminary data were obtained from 5 adult CI users, two of whom were bilaterally implanted, for a total of 7 ears. Mean pitch discrimination in the constant-vowel condition was superior with VR stimulation compared with AM stimulation, and this difference was significant. In the variable-vowel condition, mean pitch discrimination was also significantly improved with VR stimulation compared with AM stimulation. Pitch-timbre confusions were reduced with VR stimulation compared with AM stimulation, such that mean pitch discrimination in the variable-vowel condition was comparable to performance in the constant-vowel condition with VR stimulation.

Conclusions: Preliminary results suggest that VR stimulation provides superior pitch discrimination and reduced pitch-timbre confusions compared with AM stimulation in CI users.

1369: THE EFFECT OF PROVIDING A SPATIALLY RESOLVED FUNDAMENTAL FREQUENCY CUE FOR COCHLEAR IMPLANT USERS

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Cochlear implants have restored hearing to more than half-a-million people around the world. Outcomes are impressive with most recipients obtaining high levels of speech recognition through their devices. Music perception, however, tends to be poorly conveyed by cochlear implants. Pitch perception is particularly diminished in cochlear implant users compared to their normal-hearing peers. It is well established that normal-hearing listeners have highly resolved complex pitch resolution when provided with spatially/spectrally resolved harmonics. The number of electrodes available in modern cochlear implants makes provision of spatially resolved stimulation of harmonic structure challenging. The present study considers how to provide cochlear implant users with a singular resolved harmonic that covaries place and rate of stimulation to enhance pitch perception. Two experiments will be presented with the first examining pitch discrimination using modulated tones to test the extent that listeners can benefit from covarying modulation and carrier frequency on a pitch ranking task. The second experiment bypasses standard clinical processing to explicitly encode fundamental frequency as a place-rate cue in the context of synthetic vowels. The results suggest that pitch perception would be improved for cochlear implant users by providing a singular resolved harmonic that consistently encodes fundamental frequency as a place-rate cue.

1411: MUSICAL EMOTION CATEGORIZATION WITH SIMULATED COCHLEAR IMPLANT HEARING

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The ability to hear and appreciate music is crucial to everyday cultural participation and likely contributes to quality of life. Among cochlear implant (CI) users, it is therefore important to not only restore the perception of speech, but also of music. Research has shown that CI users generally report sub-optimal enjoyment for music, and exhibit a high heterogeneity in their perceptual performance, often measured with recognition of melodies and pitch deviations. The present study investigated potential effects of degraded sound, as it can occur in CIs, on the perception of emotions when listening to classical music. In particular, we manipulated carrier type (sinewave, noise), and filter order (4th, 12th) to simulate different levels of spectral resolution. The musical stimuli conveyed one of four emotions (joy, sadness, fear, serenity), which were chosen to correspond to high and low levels of arousal, and to positive and negative valence. The discriminability of each emotion was estimated through the sensitivity index (d') and from the response bias (c).

Data indicate firstly that categorization accuracy was above chance level for all experimental conditions. Secondly, both vocoder parameters produced significant main effects, suggesting that both a sinusoidal carrier more than noise carrier, and steeper than shallower filters lead to better accuracy in music emotion categorization. Thirdly, in degraded conditions, the error pattern exhibited by the participants was systematic rather than random. A subsequent feature-information-transmission analysis indicated that information about the arousal were predominant in the decision process, while valence was not transmitted properly. These results were also reflected in the analysis of d' and c, which showed a higher discriminability for joy and fear, both emotions of high arousal, and a bias against sadness and serenity, both emotions of low arousal.

To summarize, it seems that participants benefited from pitch-related cues provided by the sinusoidal carrier and from increased signal clarity provided by steeper filters. The simulation results, thus, imply that this task can be taken by CI users, but spectral resolution and transmitted pitch cues will likely play a determining role. Importantly, while valence information was not recognizable in the manipulated signal, arousal information seemed to be preserved and available within all experimental conditions. It implies that, perhaps, emotional content of certain types of music, for example one with many arousal cues, could be more accessible for CI users than others, potentially contributing to improved music listening and enjoyment.

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1416: USING MUSICAL PITCH INTERVAL COMPARISONS TO ASSESS COCHLEAR IMPLANT FREQUENCY-TO-PLACE MAPS

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Music perception remains challenging for many cochlear implant (CI) recipients, due perhaps in part to the frequency mismatch that occurs between the electrode-neural interface and the frequencies allocated by the programming. Individual differences in ear anatomy, electrode array length, and surgical insertion can lead to great variability in the positions of electrodes within the cochlea, but these differences are not typically accounted for by current CI programming techniques. Flat panel computed tomography (FPCT) can be used to visualize the location of the electrodes and calculate the corresponding spiral ganglion characteristic frequencies. Such FPCT-based CI frequency mapping may improve pitch perception accuracy, and thus music appreciation, as well as speech perception. The present study seeks to develop a behavioral assessment metric for how well place-based pitch is represented across the frequency spectrum. Listeners were asked to match the pitch interval created by a three-tone sequence (low-high-low) across different frequency ranges to estimate the extent to which the pitch map is evenly distributed across the CI array. This test was piloted with pure tones in normal-hearing listeners, using both unprocessed and vocoder-processed sounds to simulate both even and warped frequency-to-place maps. We hypothesized that the vocoded stimuli would be more difficult to match in terms of pitch intervals than unprocessed stimuli, and that a warped map (as may occur with current clinical maps) would produce poorer matches than a veridical and even map (as may be achieved using FPCT-based frequency allocation). Preliminary results suggest that the task can reveal differences between veridical and warped maps in normal-hearing listeners under vocoded conditions. Next steps will be to test this procedure in CI users and compare results with traditional clinical maps and FPCT-based frequency allocation to determine whether the new FPCT-based maps result in improved pitch-interval perception.

1423: EVALUATION OF COCHLEAR IMPLANT (CI)-MEDIATED MUSIC PROCESSING USING ELECTRODOGRAM MAPPING TO COMPARE WITH PERCEPTION

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Appreciating and perceiving music has been a persistent challenge for cochlear implant users (CIs). Despite having speech perception capabilities in quiet environments, CI users struggle with foundational components of music like pitch discrimination and in many cases are unable to enjoy music to the same degree previously. This study seeks to provide a methodology to analyze the spectral differences between musical notes and instruments after processing by the cochlear implant. We hypothesize that comparing cochlear implant processed signals (electrodograms) of different musical instruments and notes will match the performance of cochlear implant users when tasked with distinguishing musical signals from one another.
In this study, we used an electrodogram analysis to visualize and quantify musical signals processed by a 16-channel cochlear implant speech processor using the Bionic Ear Programming Software (BEPS+) provided by Advanced Bionics. Signal processing strategies have previously been proposed to affect music perception, so we focused on two commonly used CI strategies: HiRes and Optima. We used wav files from the Clinical Assessment of Music Perception (CAMP) test that provided comparable pitch and timbre between common instrument families. We additionally sampled 2 other sources of the same instruments and notes to compare signal processing strategies. A correlogram was computed comparing the electrodograms representing musical notes and the notes within an instrumental group was used to quantify the similarities and differences of the electrodograms. This provided an overall correlation, determining which instrument and/or note was predicted to be the most distinguishable from the others.

We found that lower frequency notes from the CAMP sample instruments had lower correlations. When comparing different instrumental groups, the clarinet had the lowest correlation, and the trumpet had the highest correlation. A two tailed, two sample t-test comparing HiRes and Optima on the multiple samples of instruments on the same notes as the CAMP study ($n=24$) was $p=0.0190$ with Optima having the lower correlation. When comparing multiple samples of the notes ($n=15$) the t-test showed $p=0.0445$ with HiRes having the lower correlation. A lower correlation suggests potentially better discrimination of instruments and notes.

Our analysis demonstrated that lower frequency notes are likely more distinguishable than higher frequency notes, which is expected considering CIs only process sounds up through 8 kHz. Our results were similar to the findings of the original CAMP study (Nimmons et al.) but may differ slightly due to some difference between our correlation analysis and human perception during a note or instrument identification test. We demonstrate that electrodogram and correlation analyses are a way towards fine-tuning the listening experience for CI users and may provide insight into what changes to musical signals could have the greatest impact on improving distinguishability of notes and instruments.

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1433: DOES THE QUALITY OF PRE-IMPLANT HEARING EXPERIENCE RELATE TO POST-IMPLANT MUSIC LISTENING EXPERIENCE?

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Cochlear implants (CIs) can aid hearing and listening in individuals who suffer from profound to severe hearing losses (Dritsakis, 2017). While there is a lot of research focus on encoding speech, there are still other aspects in CIs that need to be improved to enhance quality of life for people with CIs. One example is music enjoyment. The majority of adult CI users experience a significant decrease in music enjoyment and time spent for music listening post-implant (Lassaletta et al., 2008), with the most commonly reported issues being the sound quality and clarity of music (Leal et al., 2003). Correlations have been found between enjoyment, sound quality and listening habits before and after implantation (Looi & She, 2010), as well as between the amount of time spent on music listening and enjoyment after implantation. However, the pre-implant hearing experiences could affect post-implant music enjoyment, and this is what was studied here.

This study aims to explore the relationship between pre-implant listening experience and post implant music perception, appreciation and enjoyment.

Among the few music questionnaires developed for cochlear implant studies, the Munich Music Questionnaire (MUMU) was selected for this online study to measure the role of music in subjects' lives (which includes questions on music behavior, appreciation, perception, experience and education in CI users). A pitch discrimination task (Geurts & Wouters, 2000) was also included in the experiment to assess differences in pitch perception after implantation. Furthermore, exploratory factor analysis will be used to determine a latent variable for pre-implant hearing experience. This variable will be used to assess the relationship with music listening habits and pitch perception post implant. We will also compare music listening habits between pre- and post-lingual CI users. With auditory memory, some CI users were able to enjoy music they have previously heard pre-implant. In the future, results from this study shall be compared to EEG responses to pitch and music to uncover the underlying relationship between hearing experience and music appreciation in CI users.

1467: CHARACTERIZING THE COMPONENTS OF MUSIC THAT INFLUENCE MUSICALLY EVOKED EMOTIONS IN COCHLEAR IMPLANT USERS.

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While advancements in cochlear implant (CI) technology have allowed for the profoundly deaf to achieve excellent speech perception, the perception and appreciation of music remains a challenge for many CI users. The fundamental components of music can be divided into two categories: temporal components, which include rhythm and tempo, and spectral components, which include pitch, harmony, and timbre. Additionally, the intervals between pitches help determine the mode (major or minor) and can dramatically alter the mood or meaning conveyed in a song. Multiple prior studies have shown that although CI users are able to perceive the temporal elements in music with similar accuracy to their normal hearing (NH) counterparts, CI users have difficulty perceiving the spectral components of songs. Furthermore, a study by Ambert-Dahan et al. 2015 indicates that CI users have diminished perception of certain musically evoked emotions compared to NH listeners. Several mechanisms for these findings were postulated including deficits in perceiving the spectral elements of music. However, there has been little objective exploration into the specific components of music that may contribute to these findings.

The purpose of this study is to investigate how musical elements affect the decreased perception of emotions in music for CI users. In a first experiment, using the music materials of Ambert-Dahan et al. 2015 (originally validated by Vieillard et al. 2008), we examined emotional response to music and analyzed the contributions of musical elements including pitch and timbre. In a second experiment, using music composition software, we manipulated specific characteristics of the materials (tempo, mode, timbre) to evaluate their influence on emotional judgement.

We hypothesize that deficits in pitch and timbre are correlated with decreased perception of musically evoked emotions. Furthermore, given that major and minor mode are determined by pitch intervals, we hypothesize that for mode adjusted excerpts (major converted to minor, and minor converted to major), CI listeners will have diminished recognition of the altered emotions compared to NH listeners, with decreased recognition of the mode manipulation correlated with reduced pitch perception.

Preliminary results indicate that CI users are able to identify the components of emotions for happy songs as well as NH listeners, though CI users have diminished perception of peaceful, sad, and scary emotions.

1487: SHARP TEMPORAL ONSETS OF PIANO NOTES IMPROVE MUSICAL EMOTION RECOGNITION WITH COCHLEAR IMPLANTS

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In music, emotion is conveyed by mode (major or minor) and tempo (fast or slow) cues. To recognize musical emotions, normal-hearing (NH) listeners mainly use mode cues (i.e., pitch scales), while cochlear implant (CI) users rely heavily on tempo cues, because CIs do not convey salient pitch cues. Our previous study found a significant effect of instrument timbre on CI users' musical emotion recognition, with a piano producing better performance than a violin. Piano notes have sharper temporal onsets than violin notes. CI users may use such temporal envelope cues to identify the two instruments. It is hypothesized that sharper temporal onsets of piano notes may also enhance the perception of tempo cues and thus improve musical emotion recognition with CIs. This hypothesis was tested in this study.

Eight post-lingually deaf adult CI users with ten implanted ears were tested. For bimodal CI users, hearing aid was turned off and an ear plug was inserted into the non-implanted ear. For bilateral CI users, each implanted ear was tested separately. Eight NH adults served as the control group. Ten happy and ten sad melodies played by a piano and a violin from our previous study were used to create instrumental chimeras by combing the temporal envelope (ENV) of one instrument with the temporal fine structure (TFS) of another instrument for each melody. Piano, violin, TFSpiano-ENVviolin, and TFSviolin-ENVpiano melodies were tested in separate blocks for a two-alternative (happy or sad), forced-choice musical emotion recognition task. The testing order of instrument blocks and that of melodies in each block were both random. In addition, the four types of melodies were randomly played from trial to trial for a two-alternative (piano or violin), forced-choice musical instrument identification task.

The results showed that NH listeners' performance of musical emotion recognition was near perfect in each melody condition. NH listeners perceived TFSpiano-ENVviolin and TFSviolin-ENVpiano melodies to be played by piano and violin, respectively. CI users had significantly better musical emotion recognition for piano melodies than for violin melodies, consistent with our previous finding. For CI users, TFSviolin-ENVpiano melodies produced significantly better musical emotion recognition than violin melodies, while TFSpiano-ENVviolin melodies produced significantly worse musical emotion recognition than piano melodies. CI users had near perfect musical instrument identification for piano and violin melodies. Their instrument identification responses were 70% violin and 30% piano for TFSviolin-ENVpiano melodies, and 35% piano and 65% violin for TFSpiano-ENVviolin melodies.

These results suggest that NH listeners use temporal fine structure cues to achieve robust musical emotion recognition and instrument identification. In contrast, CI users rely more on temporal envelope cues to perform both tasks. It was the sharper temporal onsets of piano notes that produced better musical emotion recognition for piano melodies than for violin melodies.

1504: EXPLORING MUSIC ENJOYMENT USING SPECTRAL COMPLEXITY REDUCTION AND VARYING MUSICAL INSTRUMENTS FOR COCHLEAR IMPLANT LISTENERS

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Although cochlear implants (CIs) have enabled high levels of speech perception, improving music accessibility still remains a difficult task. However, recent developments in music enjoyment for CI listeners have shown promising results. Methods such as spectral complexity reduction and music remixing have resulted in music that CI listeners rate as more preferable than unprocessed versions. An earlier study explored the effects of spectral complexity reduction and the number of instruments on music enjoyment for normal hearing (NH) listeners using vocoded samples (Brueggeman and Hansen, 2020). The results showed a preference for fewer instruments (with non-vocal, instrumental only audio), but spectral complexity was not found to be a significant factor for the simple instrumental dataset generated based on the nursery rhyme, “Twinkle Twinkle Little Star.” Here, the evaluation was extended to include CI listener evaluation, as well as a more diverse music dataset containing vocals and a variety of instruments. The experimental protocol utilized the MUSDB18 dataset which consisted of multitrack versions of songs from various genres to present listeners with variations of each musical composition, as each song can be separated into its vocals, drums, bass, and other content. A modified MUSHRA (MUltiple Stimuli with Hidden Reference and Anchor) method was used to present our listening experiment to CI and NH listeners to rate their enjoyment of music samples in comparison to a reference. Results from CI and NH listeners will be discussed and implications for spectral complexity reduction methods for CI users will be provided. This work was supported by Grant No. R01 DC016839-02 from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health, and by the National Science Foundation Graduate Research Fellowship under Grant No. 1746053 (Brueggeman).

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1518: OPTIMIZING VIBRO-TACTILE MUSIC ENHANCEMENT FOR COCHLEAR IMPLANT USERS

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Our project aims at improving the overall musical experience of cochlear implant (CI) users by providing haptic stimulation via the skin in addition to the cochlear implant stimulation. Existing commercial devices have claimed to enhance listeners' musical experiences through a vibrating wearable wristband, vest or chair. However, the possible perceptual mechanisms supporting this claimed effect are not well-known. The aim of the experiment was to understand what perceptual mechanism vibro-tactile devices use to enhance music in order to optimize a future device for CI users. A vibro-tactile device with a single actuator was designed to be held between the thumb and forefinger. Musical audio-tactile stimuli were presented via the combination of over-ear headphones and the tactile stimulator. The frequency, intensity, and timing of the vibrations were co-varied with their equivalent auditory perceptual dimensions: pitch, intensity, and rhythm. Degraded versions of the stimuli were then created by altering the physical features of the tactile stimulation to be incongruent with the audio. Twenty participants with normal hearing thresholds (NH) and 15 participants with CIs were asked to rate music stimuli with the device alongside the degraded versions of the same stimuli in a MUSHRA-like format. Ratings were averaged across participants and compared when the audio and tactile components of each stimulus dimension were either congruent or incongruent. A drop in ratings was found for NH participants when audio-tactile intensity congruence was removed, and when the audio and tactile stimuli were misaligned in time. Therefore, the results imply the music enhancement effect of vibro-tactile devices in NH users is derived mostly from audio-tactile time alignment and intensity congruence, rather than frequency congruence. First results of CI users indicate a similar pattern, suggesting future vibro-tactile devices for CI users should prioritize audio-tactile time alignment and intensity congruence.

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