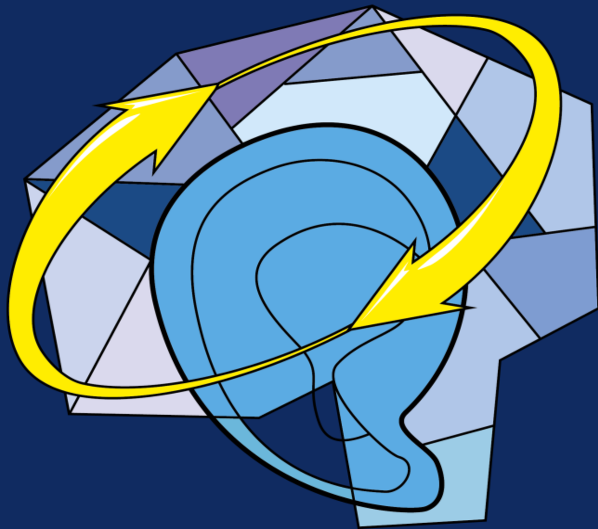
Closing the Auditory (Efferent) Loop

International Symposium



Herrenhausen Palace, Hannover

Monday, October 26 - Wednesday, October 28, 2015

Organizing Committee

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WELCOME

We would like to welcome you to the first Symposium Closing the Auditory (Efferent) Loop!

In the future of hearing aids and implants, which actually help deaf new-borns as well as the aging society, Brain Computer Interfaces will once be needed to make a last big leap to full hearing restoration. It will achieve, in a nutshell, the revived cocktail party capability. However this may take us 10 to 15 years from now. While both academia and industry are convinced that such solutions will truly appear, many currently refrain from entering this transdisciplinary, long and unknown field of research and development.

Similar to last centuries' computer chip development, a road mapping action can pave such a way. It will define challenges, critical experiments and milestones on a pre-competitive basis. New research collaborations as well as joint funding programs are initiated.

As we come from existing clinical practice, we reflect mature hearing aids or restauration systems and pursue precisely defined objectives. Thus our activity can be seen distinct from other BCI road mapping activities of more general and philosophical nature.

The symposium is sponsored by the German Volkswagen Foundation and will be held in the famous Herrenhausen castle in Hannover within a rewarding framework.

In the 19th century, Herrenhausen Palace served as the summer residence of the Royal House of Hanover (now spelled and internationally marketed as "Hannover", as in German). In 1943, the palace was air-bombed and completely destroyed, with only its once grand outdoor staircases left partly standing. The palace's renaissance began taking shape with an architecture competition in 2009/2010 – a competition which culminated in the palace's reopening at the beginning of 2013.

CONFERENCE PROGRAM

Monday 26th of October

17:00 – 18:00	Registration	Foyer
18:00 – 18:30	Welcome Th. Lenarz, T. Doll	Lecture Hall
18:30 – 22:00	Get together ***with buffet and drinks***	Foyer

Tuesday 27th of October

08:45 – 09:00	Overview – planned activities T. Doll, M. Knipper	Lecture Hall

09:00 – 12:30	**Plenary Talks** *(Chair: Ray Meddis, Enrique Lopez-Poveda)*	Lecture Hall
09:00 – 09:30	Clinical research - State of the Art, Limitations and Outlook Th. Lenarz	
09:30 – 10:00	Neurophysiology of the healthy auditory system - basic research and possibilities for closing the loop M. Knipper, Prof. M. Malmierca, R. Nouvian	
10:00 – 10:30	Signal Processing and Audiology A. Limberger, B. Shinn-Cunningham	
10:30 – 11:00	***coffee break***	Foyer
11:00 – 11:30	Modelling and System Integration W. Hemmert, R. Meddis	
11:30 – 12:00	Neuro surgery J. Krauss	
12:00 – 12:30	Expert round E. Altenmüller, B. Kollmeier, D. Ryugo	

12:30 – 13:30	***lunch*** ***Group picture***	Hall upstairs
13:30 – 18:00	**Track A – Talks** *(Chair: S. Denham)* Senior researcher	Lecture Hall
13:30 – 13:45	Towards a Closed-loop Cochlear Implant M. McLaughlin	
13:45 – 14:00	Reinstating contralateral medial olivocochlear reflex with cochlear implants E. A. Lopez-Poveda	
14:00 – 14:15	Cognitive control of a hearing aid: why and how? A. de Cheveigne	
14:15 – 14:30	Activation of group I mGluRs enhances efferent inhibition of inner hair cells in the developing cochlea of the rat S. Pyott	
14:30 – 14:45	Auditory sensory deprivation and cortical reorganization in children and adults A. Sharma	
14:45 – 15:00	Scene analysis in the aging auditory system A. Bendixen	

15:00 – 15:30	***coffee break***	Foyer
15:30 – 15:45	In-ear modification of spatial hearing M. Schönwiesner	
15:45 – 16:00	Impact of efferents on binaural hearing and bilateral implantation B. Laback	
16:00 – 16:15	Efferent pathway: Top-down feedback from cortex to cochlea P. Delano	
16:15 – 16:30	New electrode arrays for Brain Computer Interfaces Th. Stieglitz	
16:30 – 16:45	Auditory Brain Computer Interfaces M. Tangermann	
16:45 – 17:00	Recording EEG from the ear P. Kidmose	
17:00 – 17:15	Fast measurement of efferent adaptation in humans E. Dalhoff	

17:15 – 17:30	Audiovisual plasticity and speech recovery after cochlear implantation in postlingual adult deaf patients P. Barone	
17:30 – 18:00	Wrap-up	
13:30 – 18:00	**Track B – Tutorials, Poster Session, Talks** PostDocs and PhD Students	Seminar room 5
13:30 – 15:00	Tutorials	
13:30 – 14:00	Tutorial 1 - Signal Processing W. Nogueira	
14:00 – 14:30	Tutorial 2 - CI Electrode Technology G. Paasche	
14:30 – 15:00	Tutorial 3 - Brain Computer Interface Technology M. Bleichner	
15:00 – 16:00	***Coffee Break* including Poster Session**	Foyer

16:00 – 18:00	Short Talks
16:00 – 16:15	Invasive or invisible? Different approaches for controlling hearing aids with neural signals M. Bleichner
16:15 – 16:25	Language-Related Cues for the Efferent Pathway - Limitations or Research Opportunities? R. Carroll
16:25 – 16:35	Linguistic Experience and Cognitive Skills: What can real-life speech variability tell us about hearing with a cochlear implant? T. Tamati
16:35 – 16:45	Effects of efferents on neural SNR and spatial hearing: Implications for Cis S. Srinivasan
16:45 – 17:00	break
17:00 – 17:10	Optogenetic stimulation of the cochlea: Making use of a device-tissue interface with less cochlear spread of excitation T. Harczos
17:10 – 17:20	Identification of access routes and implantation sites Ph. Wimmer

17:20 – 18:00	Open discussion	
18:00 – 19:00	***dinner***	Hall upstairs
19:00 – 20:30	**Open Lecture** **Would Beethoven have benefitted from today's cochlear implants?** Professor Dr. Dr. h.c. H.-P. Zenner	Lecture Hall
20:30 – 21:30	Get together ***with drinks***	Foyer

Wednesday 28th of October

08:45 – 9:00	Working across disciplines and planned activities T. Andringa, S. Debener	Lecture Hall
09:00 – 11:00	**Road Mapping Workshop** All participants	Seminar rooms **3, 4, 5, 6**

Patient Studies and Plasticity Chair: A. Kral, A. Sharma	Seminar room **4**
Neurophysiology and Animal Studies Chair: M. Malmierca, R. Nouvian, L. Rüttiger	Seminar room**3**
Anatomy and Surgery Chair: M. Beauchamp, B. Hirt, J. Krauss	Seminar room **5**
Psychology, Psychophysics and Audiology Chair: A. Bendixen, Ch. Braun, H. Maier	Seminar room **3**
Signal Processing and Coding Chair: S. Doclo, J. Chalupper	Seminar room **6**
Modeling Chair: S. Denham, Tr. Jürgens	Seminar room **4**
Technology and System Integration Chair: E. Dalhoff, Th. Stieglitz, J. Voix	Seminar room **5**
Brain Computer Interface Chair: M. De Vos, M. Tangermann	Seminar room **6**

11:00 – 12:00	Wrap up Chairs	Lecture Hall
12:00 – 13:00	***lunch***	Hall upstairs
13:00 – 14:00	**Track A – Individual statements about future contributions** (Senior researcher, optional for PostDocs)	Lecture Hall
13:00 – 14:00	**Track B – Career Development for PhD Students and PostDocs** B. Glasmacher	Seminar room 5
14:00 – 15:00	Wrap up and panel discussion T. Doll, M. Höfer, M. Knipper, D. Ryugo	Lecture Hall
15:00	**End of Symposium / Farewell**	

Clinical research - State of the Art and Limitations

Thomas LENARZ

An overview will be provided on CIs, ABIs and AMIs (affected area, working principle) together with a rigorous analysis of the patient outcome. Moreover an overview is given on software features that already help the patients to survive in daily situations. Tests during surgery and training/fitting are described. What are clinician's suggestions for closing the loop?

Thomas Lenarz is a trained ENT-surgeon and head of the ENT-clinic at the Medical School in Hannover. Further, he is deputy coordinator of the Cluster of Excellence Hearing4all working on improving audiological diagnostics and individualized treatment of hearing loss.

Neurophysiology of the healthy auditory system - basic research and possibilities for closing the loop

Marlies KNIPPER, Manuel MALMIERCA, Regis NOUVIAN

The current knowledge of differential efferent functions on auditory nerve fibers, its influence on subcortical (inhibitory) circuitries, auditory fidelity and sound processing (mice and men) is discussed.

Marlies Knipper is professor of Molecular Physiology of Hearing at the University of Tübingen where she studies inner ear development, the mechanisms behind acoustic trauma and synaptic plasticity.

Manuel Malmierca directs the Auditory Neurophysiology Laboratory at the University of Salamanca. He focusses on brain processes that mediate adaptation and coding of auditory patterns.

Régis Nouvian tries to decipher the molecular determinants of hair cell exocytosis at the Institute for Neuroscience of Montpellier.

Signal Processing and Audiology

Annette LIMBERGER , Barbara SHINN-CUNNINGHAM

This talk focusses on the knowledge of the spectrum of pits and falls of tools to detect hidden hearing loss, cochlear tuning and residual differences in hearing threshold in hearing impaired patients/ CI patients. The latter might enable insight in the quality of subcortical encoding, cortical sensitivity, interaural time differences, and sound localization (and thereby could be used for preclinical loop improving approaches).

Annette Limberger is a professor at the University Aalen where she teaches digital Signal Processing, Acoustics, Hearing Aid Fitting and pediatric audiology.

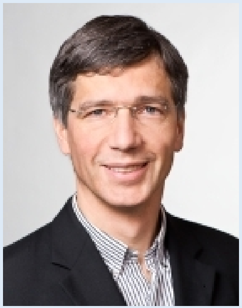
Barbara Shinn-Cunningham is a professor of Biomedical Engineering at Boston University. She is Director of the Center for Computational Neuroscience and Neural Technology. She studies auditory attention, individual differences in hearing ability, spatial hearing and crossmodal interactions.

Modelling and System Integration

Werner HEMMERT, Ray MEDDIS

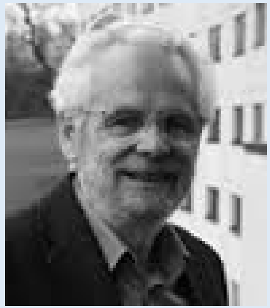
A comparative consideration of the different models of auditory pathways including their afferent and efferent part is provided. Where are the biggest lacks? And what are the most promising approaches? What is already explained by models and implemented in signal processing?

The overall question will be asked: What is modeled, not implemented, but could be implemented realistically (makes sense to use in terms of benefit for the patient)?



Prof. Werner Hemmert explores the principles of auditory information processing, develops new approached for advanced neuroprosthetics and teaches Electrical Enginering and Information Technology.

Prof. Emeritus Ray Meddis is the Director of the Essex Hearing Research Laboratory where he and his team developed a widely used model of the auditory periphery and auditory brainstem.



Neurosurgery and Anatomy

Joachim KRAUSS

The point of view of this talk will be the neurosurgical accessibility and neurosurgery chances to chronically place feedback loop simulating electrodes to either peripheral or central brain targets.

Joachim Krauss is neurosurgent by training and an expert both in general and functional neurosurgery as well as stereotaxis.

Plenary expert round

Eckart ALTENMÜLLER, Birger KOLLMEIER, David RYUGO

The panelists are asked to correlate the heard information of the plenary section to their individual view of closing the loop and challenge blind spots.

Eckart Altenmüller not only studied Music but is also a trained neurologist and now the Head of the Department of Music-Physiology and Musician's Medicine in Hannover. He is interested in processing of music and motor learning in musicians.

Birger Kollmeier studied physics and medicine and directs the Medical Physics Section at the University of Oldenburg. Further, he is the coordinator of the Cluster of Excellence Hearing4all. He is very interested in binaural hearing with hearing aids.

Prof. Emeritus David Ryugo studies the role of neural activity on brain development and synaptic plasticity at the Garvan Institute of Medical research in Sydney of where he directs his own Lab.

ABSTRACTS (Plenary & Poster in alphabetic order)

Auditory Attention Decoding Using Noisy Reference Signals

Ali Aroudi[1], Bojana Mirkovic[1,3], Maarten de Vos[2], Simon Doclo[1,3]

[1] University of Oldenburg, Germany; [2] Institute of Biomedical Engineering, Oxford University, UK; [3] Cluster of Excellence ‘Hearing4all‘

The human auditory system has a remarkable ability to separate a speaker of interest from a mixture of speakers or to tune out interfering sounds in a noisy environment. Motivated by this observation, during the last decade a large research effort has been focused on better understanding the neural activity of the auditory system, especially regarding auditory attention. It has been shown that the cortical responses to speech are correlated with the modulation envelope of attended (and unattended) speech streams. Based on this finding, decoding the auditory attention of subjects from electroencephalography (EEG) recordings using the least squares approach has been investigated, showing promising results.

In general, for the least squares-based auditory attention decoding approach the clean speech signals of both attended and unattended competing speakers are required as reference signals, which is hard –if not impossible– to achieve using acoustical signal processing algorithms in practice. In this study, the influence of noisy reference signals on the decoding performance was investigated, showing that the decoding performance is robust to noise up to a certain signal-to-noise ratio, depending on the acoustic noise type.

Audiovisual plasticity and speech recovery after cochlear implantation in postlingual adult deaf patients

Pascal Barone

Cerveau & Cognition, CNRS Toulouse, France

The cochlear implant allows profoundly postlingual deaf patients to recover speech intelligibility through long-term adaptive processes to build coherent percepts from the coarse information delivered by the implant. However, the temporal evolution of recovery can greatly vary across subject during the first year post-implantation. Because the strategy adapted by CI users for speech comprehension is linked to the cortical crossmodal plasticity that affects the pattern of brain activity during speech processing, our approach was based on searching for brain regions whom the level activity at time of implantation is correlated with the level of auditory recovery several months later. We used PET scan brain imaging to analyse the correlation between brain activity at the moment of implantation and auditory word perception scores 6 months after the implantation. Correlations were observed in a set of areas outside the auditory cortex with the highest correlation in the right occipital cortex involved in visual processing. Other correlated areas included the posterior temporal cortex known for audiovisual integration and the left inferior frontal area involved in cognitive function including speech processing. These results show that the initial high activity of the visual cortex provides the best potential to favour auditory recuperation. In a more general perspective, the influence of the visual cortex on the efficiency of the purely auditory speech perception shown in this study suggests the existence of some neural facilitation mechanisms that link both sensory modalities. Such cooperation between different sensory modalities may be a reflection of the multisensory nature of speech processing; it supports the large set of data demonstrating an important role of visual input for speech comprehension in cochlear implanted postlingual deaf patients.

Scene analysis in the aging auditory system

Alexandra Bendixen

Chemnitz University of Technology, Germany

For closing the auditory efferent loop, it is necessary to know which aspects of auditory processing need particular attention as they are of particular difficulty for hearing-impaired listeners. This talk will focus on auditory scene analysis (that is, the ability to disentangle the signals of different sound sources in a complex mixture) and discuss which aspects of auditory scene analysis pose most significant challenges for elderly listeners. It has been assumed that the ability to disentangle concurrent sounds degrades more dramatically with age than the ability to sort sounds presented consecutively in a sequence. In contrast, our combined behavioral-EEG results show that some facets of concurrent sound segregation can remain quite intact with age, whereas some facets of sequential sound segregation show an early decline. The latter appears to be the case when sequential sound segregation requires the use of higher cognitive cues, such as regular temporal patterns amongst consecutive sounds that indicate their belonging to one sound source. Implications for our understanding of scene analysis in the aging auditory system will be discussed.

Invasive or invisible? Different approaches for controlling hearing aids with neural signals

Martin Bleichner

University of Oldenburg, Germany

Listening is not a passive process but our memories, expectations and intentions shape what we hear: We can suppress what we want to attend to and we can concentrate on specific features in a soundscape. Yet hearing devices, such as hearing aids and cochlea implants are feedforward devices, in which sounds are amplified independent of what the user wants to listen to. While modern devices allow to switch between different listening settings using a remote control, this process is often cumbersome and often leads to suboptimal results for the user.

In our research we study the possibilities of using neural signals to adjust the hearing aids to the users listening needs in a more convenient manner. We focus on recording potentially useful neural signals without interfering with the user’s daily life. Classical brain imaging techniques as they are used for research purposes are not useable for a listening device user on a daily basis due to their size and complexity. We see the alternative in either implanting the electrodes or to miniaturize the electrodes such that they can be hidden from view.

We have developed electrodes that can be placed behind and in the ear. In combination with a miniaturized amplifier and a smartphone we can record neural responses outside the lab. Such a setup could become integral part of a behind-the-ear listening device. Here I show that useful signals can be recorded with our setup and will discuss future applications.

Language-Related Cues for the Efferent Pathway - Limitations or Research Opportunities?

Rebecca Carroll

University of Oldenburg, Germany

An ambitious goal for auditory research is to develop hearing devices that can be directly controlled by the human auditory system. The hopes are to ultimately solve current problems of speech perception in acoustically challenging situations such as background noise or multiple speakers. Recent advances in cognitive neuroscience are offering neural encodings that could be used as reliable cues to steer a processor. This talk raises the question whether such neurological cues can be found for higher levels of language processing, such as word recognition in continuous (and noisy) speech. Possible limitations will be weighed against the actual necessity of the type of cue. In other words: which cues in an utterance or a multitalker conversation would be sensible and reliable enough to use for steering a processor in a hearing device? Also: would we need different (language-related) processing strategies for different patient groups?

Fast measurement of efferent adaptation in humans

Ernst Dalhoff, Dennis Zelle, Anthony W. Gummer

Hearing Research Center Tübingen, Germany

Closing the auditory loop could aim at using efferent loop function in order to adjust or shape the stimuli provided by acoustic or electric hearing aids, or to possibly restore features of the intact feedback loop such as improved speech understanding in background noise. Much of the knowledge about the efferent feedback loop has been gathered by analyzing results of animal experiments and comparison to mathematical models of the feedback loop (Brown et al. 2010). Less detailed and accurate information is available about its action in normal-hearing or hearing-impaired humans. Underlying reasons comprise demanding requirements for the SNR of the recording techniques, because measurable effects of the efferent feedback action are typically small and confounded by other physiological sources of interference. In addition, variability with time as well as additional efferent influences from neural stages beyond the brainstem have to be taken into account (Wittekindt et al. 2014). Thus, the measurement and detailed characterization of the efferent system in humans remains a challenge for the years to come and will be a prerequisite for the realization of concepts exploiting auditory loop function.

A very appropriate method to assess efferent loop action noninvasively in humans is the measurement of the ipsilateral adaptation of distortion-product otoacoustic emissions (DPOAE) (Kim et al. 2001), and we have recently developed a technique which allows the measurement of the efferent loop action while separating the two interfering sources of DPOAE, thus enhancing accuracy (Dalhoff et al. 2014). A fast version of this method providing a time resolution of <30 s shows that efferent loop action in humans is a highly time-variant process, and that short measurements can tend to lead to higher adaptation values; e.g. we measured a median adaptation of the fast component of 1.9 dB as compared to 0.67 dB in Kim et al., 2001. We address in the presentation features of measurements of efferent loop action in humans such as effect size dependence on time, attentional effects, level-dependence, dependence on other stimulus parameters, and possible research directions and solutions.

The effect of acoustics on auditory attention detection

Neetha Das, Wouter Biesmans, Alexander Bertrand, Tom Francart

University of Leuven, Belgium

When multiple competing talkers are present, normal-hearing listeners are able to attend to and understand one speaker of interest. Hearing-impaired listeners struggle with the scenario, so modern hearing instruments often include signal processing to improve the signal to noise ratio of one particular speaker. However, in a multi-speaker scenario, current systems can only guess who the desired speaker is based on some heuristics, such as, e.g., the looking direction, often leading to wrong decisions. Recently, progress has been made on decoding EEG signals of subjects listening to multiple competing talkers to conduct auditory attention detection (AAD). AAD allows to determine the attended speaker, and could be implemented in a closed-loop hearing instrument. However, there has been little focus on the auditory stimuli themselves, where often two dry speech signals are presented (one at each ear) without including realistic acoustical information. The process of listening, in the real world, involves dealing with audio signals that are transformed by the listener's head-related transfer function (HRTF).

We conducted AAD Experiments in which the subject had to focus on a story (S_1) being played in one ear, while completely ignoring the story (S_2) being played in the other. The stories where administered in dry condition (S_1 and S_2 presented separately to each channel of the headphones), as well as after HRTF filtering, simulating S_1 as a source 90 degrees to the left of the listener, and S_2 90 degrees to the right. The listener was directed to attend to one particular speaker. Decoders were designed, with the help of a training set, to reconstruct the stimulus envelope from the EEG recording. AAD was performed by finding the attended stimulus based on the difference in correlation between the reconstructed envelope from the EEG recording and those of the two stimuli. We found that the HRTF condition results in significantly higher AAD performance than the dry condition. Additionally, speech intelligibility was measured under the same set of conditions, revealing that intelligibility was much lower for the HRTF condition than for the dry condition. Therefore the improved AAD performance in the HRTF condition could be attributed to increased listening effort, leading to a higher EEG recording signal to noise ratio and therefore better decoding of attention selection.

Cognitive control of a hearing aid: why and how?

Alain de Cheveigne

Université Paris Descartes, France

The healthy auditory system extracts weak sounds from complex acoustic scenes, a skill that degrades with aging and hearing loss. Recent technology for acoustic scene analysis should alleviate such impairment, but its uptake is limited by the lack of means to steer the processing towards one source among many. Within our auditory brain, efferent pathways put peripheral processing stages under the control of central stages, and ideally we would like such cognitive control to extend to the external device. Recent progress in the field of Brain Computer Interfaces (BCI) and some promising attempts at decoding audio and ECoG, EEG or MEG streams suggests that such control might be possible. Is it? What scientific and technological hurdles need to be overcome to produce a "Cognitively Controlled Hearing Aid"?

Efferent pathway: top-down feedback from cortex to cochlea.

Paul H. Delano

Universidad de Chile, Santiago, Chile.

Efferent projections to the cochlear receptor are constituted by olivocochlear (OC) neurons. In addition to the OC system, the auditory efferent system comprises descending pathways from the auditory cortex to the cochlea, allowing modulation of sensory processing even at the most peripheral level. The olivocochlear function can be assessed by measuring a brainstem reflex mediated by auditory nerve fibers, cochlear nucleus neurons, and OC fibers. Although it is known that the OC reflex is activated by contralateral acoustic stimulation and produces a suppression of cochlear responses, the influence of cortical descending pathways in the OC reflex is largely unknown. In recent works performed in chinchillas, we have demonstrated that the auditory cortex independently modulates cochlear sensitivity and the strength of the olivocochlear reflex. In these works, the activity of the auditory cortex was manipulated by two methods: cortical inactivation and electrical microstimulation. Both types of cortical manipulations produced changes in the amplitudes of auditory-nerve compound action potentials (CAP) and cochlear microphonics (CM). In addition, the microstimulation of the auditory cortex modulated the strength of the contralateral OC reflex on CAP but not on CM responses. Moreover, these two types of corticofugal modulation: (i) on cochlear sensitivity and (ii) on the OC reflex strength were not correlated, suggesting the presence of at least two functionally different descending pathways to medial OC neurons, and possibly a third pathway to lateral OC neurons. These results demonstrate that auditory cortex electrical microstimulation independently modulates the OC reflex strength and cochlear sensitivity. Some functional consequences of the corticofugal effects on the strength of the OC reflex could be the finding of stronger reflexes in awake than in anesthetized animals, and the diminishing of tinnitus perception during stimulation of the auditory cortex in human patients.

Supported by FONDECYT 1120256 and Fundación Puelma.

Optogenetic stimulation of the cochlea: Making use of a device-tissue interface with less cochlear spread of excitation

Tamas Harczos

University Medical Center Goettingen, Germany

Novel optogenetic tools promise focused optical stimulation of spiral ganglion neurons. This approach promises substantially less cochlear spread of excitation, which is believed to be one bottleneck of current cochlear implants. Hence, optogenetic stimulation will likely enable the transfer of rich spatiotemporal patterns of excitation in the cochlea and central auditory pathway that, in turn, offer unique opportunities of research on auditory function and dysfunction.

Our lab has managed to successfully elicit and record neural responses along multiple stages of the auditory pathway using both laser and microLED illumination in the mouse, rat, and gerbil cochlea employing ChR2, CatCh, and Chronos variants of channelrhodopsin.

Our current challenges include the efficient, reliable, and safe expression of channelrhodopsinsin the spiral ganglion neurons, as well as further development of intracochlear optical stimulation technology, and the demonstration of significant functional advantage of optical cochlea stimulation over electrical stimulation.

Recording EEG from the ear

Preben Kidmose

Aarhus University, Denmark

A method for measuring electroencephalograms (EEG) from the outer ear, so-called Ear-EEG, has recently been proposed. Ear-EEG yields similar timing of event-related potential (ERP) components, similar time-frequency characteristics of spontaneous neural responses, and equal signal strength as that from conventional EEG for sources close to the ear. Ear-EEG can be measured from electrodes embedded on ear-pieces, and several practical implementations of Ear-EEG platforms, individualized as well as more generic, have been proposed. Compared with existing on-scalp systems, the Ear-EEG platform has several attractive properties: it is discreet, it is comfortable to wear and unobtrusive, it is user-friendly and can be operated and attached by the user. Ear-EEG exhibits a high degree of comfort and excellent long term wearability; thus, at the expense of a limited spatial resolution, enable robust recordings of EEG in natural environments. This presentation will introduce the ear-EEG method, show various examples of ERPs related to the auditory system, show examples of spontaneous neural responses, and reflect upon the applicability related to hearing instruments.

Characterization of Ipsilateral Masking between Acoustic and Electric Stimulation through Cochlear Implants

Benjamin Krüger, Andreas Büchner, Waldo Nogueira

Medical School Hannover, Germany; Cluster of Excellence "Hearing4all"

Everyday more people with residual hearing receive cochlear implants (CIs) to obtain electroacoustic stimulation (EAS), i.e. combined auditory stimulation delivered electrically from the CI electrodes and acoustically through the hearing aid (HA) or normal hearing system. However, it is still unknown how the acoustic and electric stimulation modalities interact with each other. This work characterizes the interaction between acoustic and electric stimulation through simultaneous masking and cone beam computer tomography (CBCT).

7 CI users with ipsilateral residual acoustic hearing at low frequencies participated in the study. 4 CI users were implanted with a Cochlear Hybrid CI24RE electrode and 3 were implanted with an Advanced Bionics HiFocus Mid-Scala electrode.

Acoustic masking on electric stimulation and electric masking on acoustic stimulation were measured psychophysically. The psychophysical task consisted of measuring the elevation in the threshold of audibility of a probe in the presence of a masker. The masking threshold elevations were measured using a 3 interval-forced-choice task (3-IFC) and a two-down one-up procedure following the same approach as Lin et al. (2011). The masker level was fixed at "most-comfortable-level" (MCL) and the probe level was adaptive.

Electrical stimulation was delivered using unmodulated pulse trains directly presented via a CI-Research-Interface. Electric pulse trains were presented at five apical electrodes. Acoustic stimulation was delivered through pure tones using headphones. Pure tones were presented at 125, 250, 500, 750, 1000 or 1500 Hz, depending on the amount of residual acoustic hearing of each CI user. When possible for each EAS CI user the geometrical properties of the cochlea were characterized from CBCT data. Electrode insertion depth and residual hearing were assessed based on post-operative CBCT scans and using the Greenwood equation.

Acoustic electric interaction was observed only in CI users having large residual hearing. Preliminary results showed a threshold elevation for acoustic probes with frequencies coinciding with the electrode positions. A mean threshold elevation of 40% of the acoustic dynamic range was observed with a maximum of 10.5 dB SPL equivalent to 57.5% of the acoustic dynamic range. One subject showed a threshold elevation for the acoustic masker condition. For the most apical electrode in the presence of a 1000 Hz and a 750 Hz acoustic masker a threshold elevation of 60% dynamic range and 7.5 dB SPL was observed.

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

Experimental settings to detect hidden hearing loss upon Auditory Brainstem Responses in rodents

Sathish Kumar Singaravelu, Sze Chim Lee, Mirko Jaumann, Marlies Knipper, Lukas Rüttiger

University of Tübingen, Germany

ABR wave amplitudes correlate to the discharge rates and number of synchronously firing auditory fibers [1]. ABR wave I represents the summed activity of the auditory nerve fibers contacting inner hair cells (IHCs) [2]. Therefore, reductions in ABR wave I indicate a dysfunction in IHCs, the auditory nerve fibers, or the synaptic transmission between IHCs and nerve fibers [3]. Degeneration of auditory fibers can occur even when audiometric thresholds are normal, e.g. following “non-traumatic” loud sound [3, 4], or over age [5]. This cochlear neuropathy has been described as hidden hearing loss, as it is not thought to be detectable using standard measures of audiometric threshold [6]. We describe the methodology to analyze the fine structure of supra-threshold ABR wave amplitude as a future diagnostic procedure to detect hidden hearing loss As the wave components of the ABR represent the amount and the synchronicity of neural activity at distinct anatomical structures along the auditory pathway [7], calculation of the wave amplitudes provides information on the integrity of the auditory periphery and central auditory system. We here also discuss the pros and cons of chances to translate the methodology to human diagnostic.

A presumptive future closing of the auditory loop needs diagnostic tools for its non-invasive functional detection in humans. The measurement of supra-threshold ABR waves, in particular also its growth function, may enable to detect spreading auditory nerve activity along the ascending pathway including its feedback loop (independent of outer hair cell function).

This work was supported by grants from the Deutsche Forschungsgemeinschaft (FOR 2060 project FE 438/5-1) and by Action on Hearing Loss, RNID G45 (Rü)

Impact of efferents on binaural hearing and bilateral implantation

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University of Wien, Austrian Academy of Sciences

Binaural input from the two ears is essential for azimuthal sound localization and provides big advantages in speech understanding in noisy environments. In many clinics bilateral supply of cochlear implants (CIs) has become the standard treatment in cases of either post-lingual or very early bilateral profound hearing loss or deafness. The benefits of bilateral compared to unilateral CI supply have been clearly established, most importantly, a rudimentary ability to localize sound sources along the left/right dimension and monaural better-ear listening advantages in speech understanding. Current bilateral CIs, however, do not provide the full advantages of binaural spatial hearing experienced by normal-hearing (NH) listeners.

A body of literature suggests that one reason for this discrepancy is the impaired sensitivity of CI listeners to interaural time differences (ITDs), which are known to be essential cues for spatial hearing in NH listeners. Studies are currently underway in our laboratory to explore new stimulation methods for improved ITD sensitivity with CIs. Another potentially important reason for this discrepancy may be the auditory efferent system which has been presumed to be important for spatial hearing in NH listeners but which is not exploited with current CIs. In particular, the medial olivocochlear (MOC) system modulates outer-hair cell amplification in the left and right ear cochleae and may enhance spatial cues. In this talk, hypotheses about the potential contribution of the MOC to basic aspects of spatial hearing and consequences of the lacking MOC feedback in current CI systems are discussed and partly evaluated by model predictions.

Analysis of simultaneous multi-electrode stimulation designs: creating independent channels

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In the last 30 years the field of cochlear implant (CI) sound coding strategies has seen a tremendous development, always in the prospect of improving speech intelligibility. These strategies can also be used to control the trade-off between speech performance and power consumption. For example multiple simultaneous electrode stimulation strategies can be used to lower the power consumption while affecting speech intelligibility in different ways. Most commercial CI strategies use sequential channel stimulation. One could add additional parallel stimulation channels such that the electrical interaction between the multiple simultaneous stimulated channels is increased. We hypothesize that electrical interaction will produce spectral/channel smearing and power savings because the electrical field of the simultaneous stimulated channels interact, producing a louder sensation than sequential channel stimulation. To test this hypothesis we implemented different strategies using the BEPS+ research interface from Advanced Bionics: (I) the commercial F120 strategy which uses sequential channel stimulation (but each channel uses two simultaneous stimulated electrodes), (II) an extended version of F120, the Paired-F120 strategy, which consists of parallel stimulation of two current-steered channels. Here the electrical field of the two current-steered channels will interact, requiring less current on each current-steered channel to perceive the same loudness as with F120. However, channel interaction between theoretically independent channels may reduce speech performance. This can be diminished by adding an inverse-phased stimulation channel (flanking electrode) between the paired current-steered channels. This strategy is termed (III) Paired F120 with Flanks. This way a Tripled F120 and Tripled F120 with Flanks can be created. This poster will present the details of each strategy and preliminary results on CI users. For each strategy we measured Speech intelligibility using two lists of the Hochmair-Schulz-Moser sentence test. Spectral smearing was assessed by spectral ripple discrimination with two modulation depths at two ripples per octave ratios.

Reinstating contralateral medial olivocochlear reflex with cochlear implants

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In natural hearing, the medial olivocochlear reflex (MOCR) dynamically adjusts cochlear mechanical gain and compression, something that is thought to facilitate speech intelligibility in noisy environments. Cochlear implants (CIs) restore hearing by direct electrical stimulation of the auditory nerve and thus its users do not benefit from the benefits of the MOCR. Here, we present a bilateral sound coding strategy that reinstates the effects of the contralateral MOCR with CIs and assess its benefits for understanding speech in competition with noise. Pairs of bilateral sound processors were constructed to mimic or not mimic the effects of the MOCR. For the non-mimicking condition (STD strategy), the two processors in a pair functioned independently of each other. When configured to mimic the effects of the MOCR (MOC strategy), the two processors communicated with each other and the amount of compression in a given frequency channel of each processor in the pair decreased with increases in the output energy from a corresponding frequency channel in the contralateral processor. We asked three bilateral CI users and two single-sided deaf CI users to recognize sentences in simulated free-field conditions in the presence of a steady-state noise with a speech-like spectrum. Performance was compared for the STD and MOC strategies using the speech reception threshold (SRT), in unilateral and bilateral listening conditions, and for various spatial configurations of the speech and noise sources. Mean SRTs were at least 2 dB lower with the MOC than with the STD strategy when the speech and the noise sources were at different spatial locations. SRTs improved with increasing spatial separation between the speech and noise sources and the improvement was significantly greater with the MOC than with the STD strategies. The mutual inhibition of compression provided by the mimicking of the MOCR significantly improved the intelligibility of speech in noisy environments and enhanced the spatial release from masking. The MOC strategy as implemented here, or a modified version of it, may be usefully applied in CIs and in hearing aids.

Towards a Closed-loop Cochlear Implant

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KU Leuven, Belgium

Cochlear implants (CIs) are arguably the most successful neural prosthesis. In spite (and in some cases because) of this success, the CI research field is faced with a number of important challenges: 1) For a user to achieve good speech perception the stimulation parameters must be individually fit. 2) As the number of CI users grow it becomes difficult for audiologists to individualize each fit. 3) Pediatric CI users, a rapidly growing population, cannot provide verbal feedback on the fitting quality and as a result may not experience the full benefit of a CI. A few years ago we outlined a design for closed-loop CI [1] which may offer a potential solution to these problems. We showed that it was possible to extend the range of signals that could be recorded through a standard CI to included responses from the auditory cortex. We proposed a design for a closed-loop CI which automatically monitors neural responses from different levels in the auditory system and then uses this information to optimize fitting. Optimization could happen in a static way (similar to conventional open-loop fitting) were parameters are set and fixed at initial switch-on; and in a dynamic way were stimulation parameters are subtly adapted based on continuous neural feedback. In more recent work, we have developed cortical neural metrics which can accurately and objectively predict a CI user's speech perception [2]. These metrics could be integrated into a closed-loop CI system to automatically determine the stimulation parameters that give the best speech perception outcomes. There remain many challenges to overcome before the field can realize the full potential of a closed-loop CI. Three of the most pressing may be: 1) Improved onboard CI recording capabilities with longer recording buffers, flexible sample rates, high quality amplifiers with better artifact handling and dedicated recording electrode configurations. 2) An improved understanding of the link between neural responses and speech perception outcomes. 3) An improved electrode-neuron stimulation interface capable of fully delivering the (potentially subtle) benefits of closed-loop CI system.

Implications for attended speech reconstruction with EEG in daily life situations

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Recent studies have provided evidence that temporal envelope driven speech decoding from high-density electroencephalography (EEG) and magnetoencephalography recordings can identify the attended speech stream in a multi-speaker scenario. Transferring this method to an online scenario used in a naturalistic setting would be desirable but requires robust and low channel EEG technology. Aiming towards this goal, the present work replicated a previous study (O'Sullivan et al., 2014, Cerebral Cortex) and investigated the necessary technical requirements for practical attended speech decoding with EEG. Twelve normal hearing participants attended to one out of two simultaneously presented audiobook stories, while high density EEG was recorded. Offline analysis closely replicated the results presented by O'Sullivan et al. In addition, an iterative procedure eliminating those channels contributing the least to decoding provided insight into the necessary number and individually optimal channel layout, and revealed the optimal cross-subject channel configuration as well. On average, decoding accuracy was stable from 96 channels down to 25. Furthermore, aiming towards the future goal of near real-time classification with an individually trained decoder, the minimum duration of training data necessary for successful classification was determined using a chronological cross-validation approach. For less than 15 min of training data, subject-independent (pre-trained) decoder revealed better performance than an individually trained decoder did. Our study complements previous research and provides information suggesting that efficient low-density EEG online decoding is within reach, accomplishing an important milestone on the way to BCI steered hearing aid.

Exemplary animal models approving supra-threshold Auditory Brainstem Response (ABR) wave analysis to detect hidden hearing loss

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ABR wave amplitudes correlate to the discharge rates and number of synchronously firing auditory fibers [1]. ABR wave I represents the summed activity of the auditory nerve fibers contacting inner hair cells (IHCs) [2]. Therefore, reductions in ABR wave I indicate a dysfunction in IHCs, the auditory nerve fibers, or the synaptic transmission between IHCs and nerve fibers [3]. Degeneration of auditory fibers can occur even when audiometric thresholds are normal, e.g. following “non-traumatic” loud sound [3, 4], over age [5], or through genetic modifications [6]. This cochlear neuropathy has been described as hidden hearing loss, as it is not thought to be detectable using standard measures of audiometric threshold [7]. We here present examples of animal models in which the analysis of supra-threshold ABR wave amplitude was used to detect hidden hearing loss. We demonstrate the correlation of supra-threshold ABR wave amplitudes in animal models for Tinnitus, Hyperacusis, age-related hearing loss and genetically modified mice with functional or morphological paradigms. These applications of ABR wave amplitude analyses demonstrate that animal models can crucially contribute to further development of differential diagnostic procedures and therapeutic measures of hidden hearing loss.

A presumptive future closing of the auditory loop needs diagnostic tools for its non-invasive functional detection in humans. The measurement of supra-threshold ABR waves, in particular also its growth function, may enable to detect spreading auditory nerve activity along the ascending pathway including its feedback loop (independent of outer hair cell function).

This work was supported by grants from the Deutsche Forschungsgemeinschaft (FOR 2060 project FE 438/5-1) and by Action on Hearing Loss, RNID G45 (Rü).

Activation of group I mGluRs enhances efferent inhibition of inner hair cells in the developing cochlea of the rat

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Cholinergic neurons in the medial olivocochlear (MOC) nucleus in the brainstem supply inhibitory efferent innervation to the inner hair cells (IHCs) in the developing cochlea and the outer hair cells (OHCs) in the mature cochlea. We combined electrical stimulation of these efferent fibers and patch clamp recordings from the IHCs to measure MOC-IHC efferent synaptic strength in the developing cochlea. We find that application of mGluR agonists or release of glutamate from the IHCs enhances MOC-IHC efferent inhibition, likely by acting on group I mGluRs present on the efferent presynaptic terminals. These findings suggest the presence of a local negative feedback loop: IHC activity enhances MOC efferent synaptic strength which, in turn, likely suppresses IHC activity. This feedback loop has important implications for activity-dependent maturation of the cochlea as well as functioning of the MOC-OHC efferent synapses in the mature cochlea.

In-ear modification of spatial hearing

Marc Schönwiesner

University of Montreal, Canada

There is a new push in neuroscience and psychology to move experiments out of the highly controlled, but often artificial, laboratory environment and into the complex, multisensory, and poorly controlled real world. I will discuss two experiments that modify spatial hearing and track adaptation and brain plasticity in response to the modification. In the first experiment, we use digital earplugs to add a delay to sounds arriving at one of the ears, which shifts an important cue for horizontal sound localization, interaural time differences. In the second experiment, we use silicon ear molds to change the shape of the outer ear and modify the spectral cues for vertical sound localization. Participants wear the digital earplugs or silicon molds for several days in their normal day-to-day environments. We track behavioral adaptation by repeated psychoacoustical testing and we measure single-voxel tuning to sound directions in auditory cortex before and after adaptation. Adults adapted surprisingly rapidly to drastic changes in localization cues and sensory-motor training appears to improve adaptation. Even with training, individuals differ greatly in their capacity for adaptation. Adaptation to modified sensory input is likely a function of the efferent pathways. This form of plasticity is thus an example of closing the auditory loop.

Auditory sensory deprivation and cortical reorganization in children and adults

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A basic tenet of neuroplasticity is that the brain will re-organize following sensory deprivation. Auditory deprivation appears to tax the brain by changing its normal resource allocation. A better understanding of cortical re-organization accompanying hearing loss may allow us to improve the design and fitting of hearing devices, to allow them to better accommodate altered cortical processing. Compensation for the deleterious effects of hearing loss includes recruitment of alternative brain networks during cortical processing. Our EEG experiments suggest that hearing loss results in significant changes in neural resource allocation, reflecting patterns of cross-modal compensation, increased listening effort, and decreased cognitive reserve. Our results suggest that compensatory plasticity starts in early stages of hearing loss and significantly influences outcomes with hearing aids and cochlear implants for adults and children with hearing loss.

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Effects of efferents on neural SNR and spatial hearing: Implications for CIs

Sridhar Srinivasan and Bernhard Laback

University of Vienna, Austria

The release from masking of signals in noise by the medial olivocochlear reflex (MOCR) has been studied at various levels of the brain stem, such as the cochlear nucleus and the inferior colliculus. This selective decrease of the neuronal responses to noise and the enhanced signal representation is thought to aid in the detection of signals such as tones or speech in noisy situations. While some studies report positive correlations between the MOC reflex strength and the performance accuracy in speech-in-noise detection, recent studies also report negative correlations and propose the involvement of top-down effects, such as selective attention, via the cortico-olivocochlear pathway in benefiting speech-in-noise processing. Mammals are thought to localize sounds in space by means of interaural time and level differences at low and high frequencies, respectively. In normal hearing listeners' sound localization is rather robust to interference from noise sources. It is assumed that the efferent system plays an important role in unmasking and preserving the spatial cues required for sound localization in noise. In cochlear implant listeners, the MOC reflex pathway is bypassed and hence may not contribute to unmasking and preserving spatial cues in noisy situations. It is unclear to what extent, the lack of the MOC reflex pathway and consequently the limiting of top-down effects mediated via the cortico-olivocochlear pathway might affect spatial hearing in noise. Hypotheses on these questions and experiments to address them will be discussed. Furthermore, the issue of whether and how, long-term compensatory mechanisms of signal-in-noise processing may arise in the ascending auditory pathways and across the other descending higher order pathways will be discussed.

New Electrode Arrays for BCIs

Thomas Stieglitz

University of Freiburg, Germany; IMTEK

Electrode arrays in brain-computer-interfaces (BCI) establish a functional interface between a technical system and biological target tissue – the brain – to record electrical signals or to stimulate nerve cells. So far, clinical applications have been established in targeting and stimulating deep brain structures to alleviate symptoms in Parkinson's disease and to record signals from the brain in epilepsy patients to locate the seizure focus and decide about surgical interventions. Research in the last decade has gone beyond precision mechanics devices and introduced micro- and nanotechnologies to design and develop novel devices with higher densities of electrodes, integrated light sources and sensors and sometimes wireless energy supply and data transmission to get rid of percutaneous cables. A plethora of electrode designs has been developed with micromachining technology for neuroscientific applications using either stiff or flexible substrates.

This talk will give an overview how electrode designs could and should look like to interface with different structures in the brain: epicortical, intrasulcal but also intracortical, mid- / deep brain and nerve interfaces will be presented. Electrodes for recording and stimulation allow closing the efferent loop but need to meet the target specifications to match the desired neural target structure with respect to surgical access, size, spatial resolution and connection to control electronics. Examples of flexible arrays and results of biostability and functionality will be discussed. Finally, concepts and first results of multimodal devices will be presented that include optical components like waveguides for optogenetics and chemical sensors for metabolic monitoring.

Lip-reading and multi-sensory integration abilities in hearing-impaired individuals – Validation of audio-visual speech stimuli

Maren Stropahl[1], Sebastian Schellhardt[2] ,Stefan Debener[1,3]

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There is converging evidence that the auditory cortex takes over visual functions during a period of auditory deprivation but until now it is unclear when this reorganization process begins, and how it impacts on hearing restoration. To better understand the process and the development of cortical cross-modal reorganization, investigations with normal hearing, moderately hearing impaired individuals and cochlear implant (CI) users are needed. Aiming towards this goal audio-visual integration can be assessed in hearing impaired and normal hearing individuals. Audio-visual integration of speech is frequently investigated with the McGurk effect. Incongruent presentation of auditory and visual syllables may result in a fused percept of visual and auditory information. However, perception of the McGurk effect depends strongly on the stimulus material used, making comparisons across groups and studies difficult. To overcome this limitation we developed a large set of audio-visual speech stimuli, consisting of eight different speakers (4 females and 4 males) and 12 syllable combinations. The quality of the material was evaluated with 24 young and normal hearing subjects. In addition, the McGurk effect was studied in eight adult CI users and compared to the normal hearing group using a probabilistic model. The comparison confirmed previous reports of stronger audio-visual integration in CI users. The audio-visual material developed in this study further consists of monosyllabic words and short sentences and will be made freely available. The investigation of changes in audio-visual information processing in hearing impaired individuals might help to further understand the underlying mechanism of cortical reorganization and restoration of the hearing system which eventually affects the efferent auditory system.

Linguistic Experience and Cognitive Skills: What can real-life speech variability tell us about hearing with a cochlear implant?

Terrin N. Tamati

University Medical Center Groningen, Netherlands

Speech communication is an important part of daily life for humans, providing us a way to connect with other people and the surrounding world. Yet, everyday, real-life listening conditions can be very challenging. Beyond background noise and competition, listeners must deal with source degradation in the form of speech variability. For example, the pronunciation of a word differs across talkers and social groups, as well as environmental and social contexts. In the clinic, ideal speech, i.e., carefully controlled speech with clear pronunciations is commonly used to assess the speech recognition abilities of patients. In contrast to ideal speech, highly variable speech imposes a greater perceptual and cognitive demand on listeners, resulting in more challenging or effortful speech recognition, as can be measured by lower accuracy or increased response times. While robust speech perception is mostly achieved for ideal speech in most cochlear implant (CI) users, our knowledge of CI perception of highly variable speech, more characteristic of speech in real life, is still limited. Normal-hearing listeners have highly flexible perceptual systems, allowing them to adapt to differences in talkers' voices, regional or foreign accents, or speaking styles without much impact on communication. However, CI users may have extra difficulty adapting to the speech variability since the speech signal transmitted by a CI is inherently degraded, missing spectro-temporal details. In order to begin to address this issue, we examined the perception of different sources of speech variability by CI users and normal-hearing listeners with CI simulated speech in a series of studies. Findings from these studies shed light on CI users' speech perception abilities, and demonstrate the important role of linguistic experience and cognitive skills in the perception of highly variable, real-life speech. Furthermore, the findings suggest that the well-controlled speech conditions in the research laboratory or clinic may not reflect actual CI performance in real life. This research is important for improving our knowledge of the linguistic and cognitive components of CI speech perception, the assessment of CI speech and language outcomes, and the development of more targeted, individualized rehabilitation and training tools.

Auditory Brain-Computer Interfaces

Michael Tangermann

University of Freiburg, Germany

Brain-Computer Interfaces (BCIs) allow for single-trial analysis of mental states based on recordings of brain activity. The electroencephalogram (EEG) is the dominating source of brain signals exploited in BCI systems. Despite characterized by a low signal-to-noise ratio, EEG signals can be analyzed by machine learning methods during online applications. During the task execution, BCI systems deliver objective (yet not perfect) estimates of e.g. the level of overt and covert directed attention of a user towards visual or auditory stimuli, can decode ongoing attempts of motor execution, the execution of mental calculations etc.

The feature of BCI neurotechnology to deliver quasi instantaneous estimates of such mental states makes it an interesting tool outside the classical realm of BCIs to control an application or device. Instead, BCIs may serve for novel clinical applications, which require an objective assessment of a brain state in order to realize novel brain state-dependent treatment protocols. In the first part of my talk, I will briefly review auditory BCI approaches for communication and control. In the second half of my talk, I will present a BCI paradigm based on auditory ERP responses, which is intended for the use in rehabilitation training of stroke patients with word production deficits.

Evaluation of surgical approaches to auditory pathway

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University Hospital St. Pölten

The development of cochlear implantation has allowed the majority of patients deafened after the development of language to regain significant auditory benefit. In a subset of patients, however, problems while focusing on a particular auditory stimulus in noisy surroundings occur. This is mainly caused by the lack of efferent signals derived from the auditory pathway.

It is known that the auditory efferent system plays a crucial role in signal processing. The efferent information travels there down the cochlear nuclei, superior olivary complex of the brainstem and the inferior colliculus of the midbrain, being further processed at each waypoint. Since the efferent system of this pathway potentially provides feedback for closed loop CIs we have to investigate the possible surgical access routes.

The most commonly used access to cranial nerve nuclei and the internal auditory canal is the retrosigmoidal approach to the cerebellopontine angle and thus the brainstem. Particularly in comparison to transpetrosal approaches it provides a lower morbidity. Additional access routes should be explored and intraoperative mapping, navigation and endoscopic surgery have to be combined and optimized as well for a reliable access to efferent signals.

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Notes

Never more alas will I
hear again a babies cry.
The bird song on a summers day,
the laughter of a child at play.
The bustle of life all around,
Gone! Now, I cannot hear a sound.
Though music that I still adore will
fill the concert hall no more.
My love of it will still be fed
I hear it still inside my head.

George Bernard Hough. 2009.

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