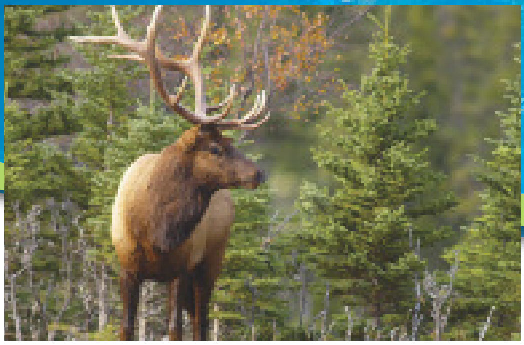
6th International Conference on Auditory Cortex

Keynote, Invited, Trainee and Poster Abstracts



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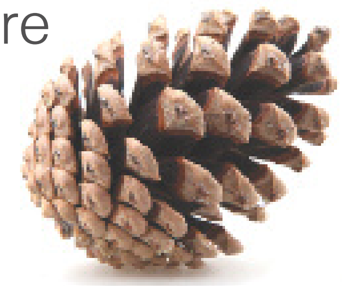

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International Conference on Auditory Cortex
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Learning to hear: Auditory perceptual learning and changes in the conceptualization of auditory cortical function

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The last 30 or so years have seen profound changes in our conceptualization of auditory cortical function, driven by the demonstration of various forms of plasticity in the auditory system. Auditory perceptual learning (APL), improvement in discriminative ability as a consequence of training, provides an instructive example of the findings responsible for these changes. Although perceptual learning had been studied in various sensory modalities for many years, it was generally assumed to involve changes in task performance rather than in sensory processing mechanisms themselves. The recognition that many forms of visual perceptual learning are specific to the region of the retina to which the training stimuli are presented or to a particular stimulus attribute led to the view that it involved changes in sensory representation at early stages of cortical processing (in primary visual cortex). "Early-stage" models of this sort have been contrasted with "late-stage" models that propose the changes take place in areas associated with decision making and the allocation of attention A number of studies of APL in animals have described changes in sensory representation in primary auditory cortex, but in other studies such changes were not observed. A possible reconciliation of these conflicting results is provided by evidence that changes in sensory representation constitute a transient stage in the processes underlying perceptual learning. Human neuroimaging studies provide some support for this suggestion, but also indicate that auditory training (e.g., in musicians) results in long-term changes in auditory cortical function. Psychophysical evidence suggests that the level at which changes occur depends on the nature of the discrimination task and the stage of training. The characteristics of APL reflect the fact that auditory cortex forms part of distributed networks that integrate the representation of auditory stimuli with attention, decision, and reward processes.

Through the jungle of sounds

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In complex auditory surroundings we rely on our expertise to recognize objects, animals and people by their sounds; on the combination of the meaning of a sound and its location; and on attending to sound objects in different parts of space. Neural representations which underlie these aptitudes and their relationship to the influential dual-stream model of auditory processing were investigated in a series of recent studies. Several lines of evidence indicate that recognition of environmental sounds involves the ventral auditory stream and proceeds through discrimination steps from broad to more narrow categories. Recent studies have investigated how high-level expertise involving fine-grained discrimination within narrow categories is acquired and how it impacts on specific steps of auditory processing. Their results highlight the importance of supramodal semantic representations in fine-grained discrimination and hence the role of top-down afferents. A series of human behavioral,

activation and lesion studies strongly suggests that in addition to the position-independent representation of the meaning in the ventral auditory stream and to the spatial representation in the dorsal stream, specific neural populations respond to sound objects as a function of their specific position. Activation studies have shown that auditory-spatial attention, similarly to visuo-spatial attention, relies on the right-dominant ventral attentional system. Its lesions are often associated with visuo-spatial and auditory neglect. One therapeutic intervention which alleviates visuo-spatial and auditory neglect symptoms consists of visuo-motor adaptation via rightward-deviating prisms. In the visual modality this effect is due to a shift of hemispheric dominance within the ventral attentional system. Recent studies indicate that similar neural mechanisms underlie the effect on auditory neglect symptoms and suggest that auditory-spatial attention is modulated by supramodal afferents.

Auditory and vocal learning in the songbird

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Adult birdsong in many species is 'crystallized' in that song is highly stereotyped in its structure and normally changes little over time. In this talk I will focus on the effects of auditory feedback perturbation on the songs of adult finches. These experiments indicate that given appropriate instruction adult birds can rapidly and adaptively modify the structure of their songs. Song modification can be elicited both by a process of externally guided reinforcement and by a process of self driven error correction. These experiments demonstrate that the remarkable stability of adult song does not reflect an incapacity for adaptive vocal modification. Rather, they indicate that adult song remains fixed due to an ongoing process of feedback evaluation in which birds match their songs to a stable sensory target. Much of the neural circuitry that subserves song production and song plasticity has been well-elucidated. Previous work has identified a primary song motor pathway that is required throughout life for normal song production and that is the presumed locus of much of the plasticity that reflects modification of song. In addition, songbirds have a simplified but conserved cortical-basal ganglia circuit (the anterior forebrain pathway, AFP) that is specialized for song. I will describe work indicating that the AFP is not required for the production of well-learned adult song. However, disruptions of the AFP prevent a variety of forms of adult vocal plasticity, indicating a crucial role for this pathway in feedback-dependent adult vocal learning. Because the AFP is a simplified cortico-basal ganglia circuit that contributes to a single, quantifiable behavior, it may prove to be a useful system for further testing mechanism whereby such circuits contribute to auditory vocal learning and to learning more generally.

Cortical control of auditory attention

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In many social settings, there are multiple, competing sounds vying for attention. The ability to separate sound streams coming from different sources and focus on whatever source you want to understand is critical for communication in such environments. This talk reviews behavioral, EEG, and fMRI studies that explore how listeners control auditory attention. Results show that when listeners decide to focus attention on a sound stream from a particular direction or from a particular talker, there is preparatory activity in various brain networks. Once the sound stimuli begin to play, the cortical representation of the competing sound streams is modulated, such that responses to an attended stream of sound is strong relative to streams that are being ignored. Importantly, if attention is focused on a sound from a particular direction vs. focused on sound with particular non-spatial sound features, seemingly similar behavioral tasks actually engage very different brain networks. The network engaged by spatial auditory attention includes prefrontal and parietal areas, while non-spatial attention engages regions associated with high-level auditory processing. By contrasting fMRI activity during comparable auditory and visual selective attention tasks, we find that the cortical networks engaged by spatial auditory attention map directly to regions that are commonly assumed to comprise a visuo-spatial attention network. Conversely, the prefrontal regions that appear to be preferentially engaged ruing auditory processing are recruited during visual tasks that require analysis of stimulus timing. Together, these results support the view that auditory inputs are naturally processed differently from visual inputs, but that the brain has the capacity to recruit different brain networks to process the same inputs, based on task demands.

Invited Speakers | Abstracts

Neuromodulation of auditory cortical processing by brain states and behavior
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Release of norepinephrine and acetylcholine into the auditory cortex (AC), concurrent with presentation of sounds, has long been known to drive reorganization of AC responses to sounds (e.g. Kilgard and Merzenich, 1998). This neuromodulation is thought to be an important mechanism of learning in auditory tasks. However, the same neuromodulatory systems fluctuate constantly to control global aspects of brain state such as arousal and alertness. How do the same neuromodulatory systems regulate both brain state and behaviorally-gated plasticity? We recently discovered that the diameter of the pupil is an extremely sensitive indicator of the state of the brain in mice (McGinley et al., Neuron 2015a,b). Small pupils are associated with slow rhythms in AC, which interfere with small and noisy sound responses; moderate pupil size associates with quiescent background activity in AC and large and reliable sound responses; while large pupils correlate with prominent high-frequency (e.g. gamma) background activity that swamps out responses to sound. We found that these trends in AC activity patterns were mirrored in behavioral performance at detecting target sounds in noise: small or large pupils were associated with poor performance, whereas moderate pupil size associated with more optimal behavior. How do neuromodulatory systems contribute to the effects of pupil-indexed brain state on AC activity and behavior? Using two-photon imaging of cholinergic (ACh) or noradrenergic (NE) axons in cortex, we found that rapid pupil changes accompany release of NE, whereas slower changes are more closely related to ACh axonal activity (Reimer, McGinley et al., Nature Communications, 2016). In ongoing work, we are exploring the behavioral correlates of these rapid pupil changes. Overall, there is a partial dissociation of time scales separating brain state effects from phasic learning signals, and rapid task-related pupil dilations (possibly indicating NE release) reflects decision bias.

In-ear modification of spatial hearing
Marc Schönwiesner[1]
[1]University of Leipzig; University of Montreal

Spatial hearing is important for scene segregation, but most of the current hearing aids drastically disturb spatial cues. I try to understand how people adapt and learn to make sense of these disturbed cues. My particular approach is to move experiments out of the highly controlled, but often artificially simple, laboratory environment and into the complex, multisensory and poorly controlled real world. I will discuss a series of experiments in which we modify spatial hearing in natural environments and track adaptation and brain plasticity in response to the modification.

Neuronal mechanisms for dynamic auditory perception

Maria Geffen[1]
[1]University of Pennsylvania

Hearing perception relies on our ability to tell apart the spectral content of different sounds, and to learn to use this difference to distinguish behaviorally relevant (such as dangerous and safe) sounds. Recently, we demonstrated that the auditory cortex regulates frequency discrimination acuity following emotional learning. However, the neuronal circuits that underlie this modulation remain unknown. In the auditory cortex, the excitatory neurons serve the dominant function in transmitting information about the sensory world within and across brain areas, whereas inhibitory interneurons carry a range of modulatory functions, shaping the way information is represented and processed. I will discuss the results of two studies that elucidate the function of specific inhibitory neuronal population in sound encoding and perception. First, we found that the most common class of interneurons, parvalbumin-positive, modulate frequency selectivity of excitatory neurons in the auditory cortex, and regulate frequency discrimination acuity and specificity of discriminative auditory emotional learning. Our results demonstrate that cortical inhibition can improve or impair acuity of innate and learned auditory behaviors that rely on frequency discrimination. Second, we found that another class of interneurons, somatostatin- positive interneurons, regulate adaptation in responses of cortical neurons to frequent sounds, in a stimulus-specific fashion. By selectively reducing responses to frequently, but not rarely, occurring sounds, auditory cortical neurons enhance the brain's ability to detect unexpected events through stimulus-specific adaptation. More recent experiments demonstrate that the specialized role of interneurons extends to other forms of adaptation. These results expand our understanding of how specific cortical circuits contribute to auditory perception in everyday acoustic environments.

How the brain forms spatial representations from vision and audition

Uta Noppeney[1]
[1]University of Birmingham

For effective interactions with a dynamic environment the brain needs to integrate sensory signals from a common source and segregate those from different sources into coherent spatial representations. To flexibly adapt to changes in the input statistics it needs to recalibrate the senses and reconcile persistent spatial disparities. Human observers have been shown to integrate sensory signals in line with Bayesian Causal Inference by taking into account the uncertainty about the world's causal structure. Combining Bayesian modeling, multivariate decoding and EEG/fMRI we show that the brain integrates sensory signals in line with Bayesian Causal Inference by encoding multiple perceptual estimates along the cortical hierarchy. Only at the top of the hierarchy, in anterior intraparietal sulcus, at about 300-500 ms the uncertainty about the world's causal structure is taken into account and sensory signals are combined weighted by their sensory reliabilities and task-relevance as predicted by Bayesian Causal Inference. Informed by causal inference in dorsolateral prefrontal cortex, the intraparietal sulcus generates audiovisual spatial representations to guide behavioural choices and motor responses. By contrast, a circuitry encompassing planum temporale and inferior parietal cortex forms auditory representations that flexibly adjust and recalibrate to the statistics of the audiovisual signals to reconcile persistent spatial discrepancies across the senses.

Hearing and listening with an aged auditory cortex

Gregg Recanzone[1]
[1]U.C. Davis

Age-related hearing loss is the third leading cause of disability in the aged, affecting over half of all senior citizens. These deficits can be either peripheral or central in origin, and individuals with 'normal' hearing can still suffer from central deficits, with the most common complaint being a reduced ability to understand speech in noisy environments. In the laboratory this translates to deficits in sound localization ability, and deficits in temporal processing ability. To better understand these deficits, we have recorded the activity of single neurons in the auditory cortex of aged and young monkeys to complex spatial and temporal acoustic stimuli. We have found profound differences in both the spatial and temporal processing capabilities between young and aged animals in both the primary auditory cortex (A1) and the caudolateral (CL) belt area. First, there is an increase in both the spontaneous activity and the driven activity in aged cortical neurons compared to young neurons in both A1 and CL. Secondly, while spatial processing in area A1 is similar in young and aged animals, the sharpening of spatial tuning is not found in area CL in the aged animals. This is in parallel with a lack of neuronal inhibition/suppression at the flanks of the spatial tuning curves in the aged neurons, suggesting that normally spatial tuning is shaped by these inhibitory mechanisms. With respect to temporal processing, we found a shift in the distribution of neurons that can significantly encode the modulation frequency of amplitude-modulated (AM) noise, from a combined firing rate and temporal code to primarily a firing rate code. The temporal precision was significantly worse in the aged neurons compared to the young ones. These differences could underlie the complex acoustic processing deficits that result in decreased speech perception experienced by the aged.

The role of the ventral prefrontal cortex in processing, integrating, and remembering face and vocal information

Lizabeth Romanski[1]
[1]University of Rochester School of Medicine

The merging and remembering of auditory and visual information occurs over a large network of cortical and subcortical regions in the brain and is an essential process in communication. One node in this network which we have focused on is the ventrolateral prefrontal cortex (VLPFC). Anatomical studies have demonstrated connections of VLPFC areas 12/47 and 45 with auditory and visual association cortices in the rostral auditory belt and parabelt, and extrastriate visual cortex. As a result of this rich audiovisual input, neurons in VLPFC exhibit robust responses to complex auditory stimuli, including vocalizations, and to complex visual stimuli including faces. Furthermore, many VLPFC neurons are multisensory. These multisensory neurons demonstrate strong responses to species-specific vocalizations and their corresponding dynamic facial gestures and exhibit integrative responses to their simultaneous presentation. In addition, VLPFC neurons are active during working memory tasks when nonhuman primates must remember face-vocalization pairs. The activity of VLPFC neurons during working memory reflects both stimulus and task factors with neural activity tied to cue, delay and response task demands. Importantly, inactivation of VLPFC, with cortical cooling, during audiovisual working memory, results in a decrease in performance accuracy. Thus, the nonhuman primate VLPFC is essential in the processing, integration, and remembering of face and vocal stimuli, processes which are critical in communication. Research focused on this nonhuman primate frontal lobe region which is specialized for the integration and remembering of communication information will help us in our efforts to understand the neural basis of working memory and communication in the human brain.

Contributions of local speech encoding and functional connectivity to audio-visual speech integration

Christoph Kayser[1]
[1]University of Glasgow

Seeing a speaker's face enhances speech intelligibility in adverse environments. We investigated the underlying network mechanisms by quantifying local speech representations and directed functional connectivity in MEG data obtained while human participants listened to speech of varying acoustic SNR and visual context in two paradigms. One study involved the presentation of long (6min) continuous texts and manipulated SNR across four levels. We found that during high acoustic SNR speech encoding as reflected by temporally entrained brain activity (mostly in delta and theta bands) was strong in temporal and inferior frontal cortex, while during low SNR entrainment emerged in premotor and superior frontal cortex. These changes in local encoding were accompanied by changes in directed connectivity along the ventral stream and the auditory-premotor axis. Importantly, in this study the behavioural benefit arising from seeing the speaker's face was not predicted by changes in local encoding but rather by enhanced functional connectivity between temporal and inferior frontal cortex. A second paradigm tested audio-visual perceptual benefits directly at the single sentence level using a word recognition task. We used single-trial decoding to characterize local representations of word identity and relied on measures of intersection information to directly link these neural representations to single trial perception. This revealed a network of superior temporal, supramarginal and inferior frontal regions, in which the neural read-out of word identity carries predictive power for perception in multisensory conditions. These findings highlight the need to consider both, local representations and functional connectivity, when trying to elucidate the neural underpinnings of speech perception and highlight how both, ventral and dorsal pathways, facilitate speech comprehension in challenging multisensory environments.

Vocal learning drives auditory development

Sarah Woolley[1]
[1]Columbia University

uditory-vocal communication requires the coordinated development of sensory and motor circuits around sounds that convey social information. When communication sounds are learned during development, the juvenile brain must build auditory and vocal motor circuits that are functionally coupled to perceive and produce the same acoustic features. Humans and songbirds learn to communicate using complex sounds during development. Behavioral studies of speech and song perception indicate that early experience of communication sounds shapes auditory processing and perception for life. We study the role of vocal communication experience in development of auditory cortex function using songbirds. I will present our studies using manipulations in song tutoring, chronic electrophysiological recording and the analysis of behavior to test: 1) relationships between juvenile experience of singing adults and development of response properties in auditory cortex neurons; and 2) differences in the impact of song experience on response properties across cortical regions.

Why does language not emerge until the second year?

Rhodri Cusack[1]
[1]Trinity College Dublin

Receptive and expressive language in infants is primitive in the first year and then develops rapidly from around 18 months old. Why there is a delay in the development of language? It might be because the brain needs time to mature before the circuitry is ready to begin processing language. Alternatively, the auditory-language system may be functioning in the first year but may need to gather experience of the acoustic environment before receptive and expressive language can be developed. To distinguish these alternatives, we used neuroimaging with MRI to probe the developing auditory language system. We examined the pathway that carries rich acoustic information from the thalamus, the connectivity of the cortical speech network, and the tuning to sound features in the cortex. We then examined motor and executive systems, which are also important in language function. We found converging evidence that many brain systems are surprisingly mature and that the auditory language system is functioning, suggesting a neuroconstructivist explanation that the delay in the development of language is due to a need to acquire experience, rather than to the immaturity of the brain.

Turtles all the way down: Reorganized sound processing in the cholinergic basal forebrain drives cortical plasticity during learning

Daniel Polley[1]
[1]Harvard Medical School / Mass. Eye and Ear Infirmary

Learned associations between sound and adverse behavioral consequences are thought to arise from a specific and lasting plasticity in the auditory cortex (ACtx). In a well-studied form of cortical plasticity, auditory conditioned stimuli (CS) are paired with aversive, unconditioned stimuli (US) and their learned association supports the emergence of sound-evoked defensive behaviors. The prevailing model holds that the critical plasticity underlying this form of learning emerges from a temporal "handshake" in the ACtx between the US trace, encoded by a surge of acetylcholine from nucleus basalis, and a CS trace that winds its way up the central auditory pathway. Here we show behavioral evidence of auditory learning and ACtx receptive field plasticity when the CS and US are separated by extended periods of time. How does the ACtx bridge the gap and enable CS-specific reorganization when the sensory trace disappears long before the cholinergic US trace arrives? New data from our lab suggests that the handshake may be occurring in nucleus basalis itself. We used an optogenetic strategy to record from cholinergic ACtx-projection neurons in the nucleus basalis of head-fixed mice during auditory conditioning while simultaneously recording from all layers of the primary ACtx. We see evidence for multiplexed encoding of auditory cues and reinforcement signals in nucleus basalis cholinergic neurons that support rapid readjustments in sound-evoked spiking during conditioning. Cortical plasticity emerges in parallel but persists long after conditioning ends, whereas the change in basalis is transient. These findings suggest that the ACtx is a critical locus for the maintenance, but not induction, of associative plasticity underlying aversive auditory learning. These findings also highlight the rapid, selective and adaptive sound processing that occurs within neuromodulatory nuclei not classically considered part of the central auditory pathway.

Can cortical plasticity compensate for abnormal hearing in childhood?

Karen Gordon[1]
[1]Hospital for Sick Children

Hearing aids and cochlear implants provide audibility to the developing brain through impaired ears. This treatment avoids major reorganization resulting from complete auditory deprivation but does not restore normal hearing. We thus ask how the developing auditory system compensates for impoverished input received through auditory prostheses. Our first objective was to assess effects of treating one ear in children who have bilateral deafness. Surface auditory cortical potential responses in unilateral cochlear implant users show remarkably similar development to normal hearing peers but source analyses in a group of adolescents who are successful users of unilateral cochlear implants reveals reorganization of activity in auditory cortices and abnormal activity in cortical areas involved in attention and spatial processing (frontal and parietal-occipital cortex). Time-frequency assessments suggest changes to cortical connectivity in responses from both the experienced ear as well as the long-deprived ear. Our second objective has been to alleviate effects of single sided hearing in children by promoting binaural/spatial hearing. Prior work revealed that early bilateral input is essential for development of bilateral pathways through the brainstem and cortex. Binaural processing was thus assessed in children who received bilateral cochlear implants simultaneously at young ages. After ~4 years of bilateral implant use, cortical effects of changing interaural timing and level differences remained significantly reduced relative to normal hearing peers. In addition, decreased parieto-occipital activity, possibly involved in spatial processing, was found. Results of both experiments reveal that auditory plasticity is promoted through early fitting and use of auditory prostheses in children with hearing loss but that effects of abnormal hearing remain. Future efforts are to better treat hearing loss by early fitting for accurate and consistent binaural cues.

The vocal brain: Cerebral processing of voice information

Pascal Belin[1]
[1]Aix-Marseille University

The human voice carries speech but also a wealth of socially-relevant, speaker-related information. Listeners routinely perceive precious information on the speaker's identity (gender, age), affective state (happy, scared), as well as more subtle cues on perceived personality traits (attractiveness, dominance, etc.), strongly influencing social interactions. Using voice psychoacoustics and neuroimaging techniques, we examine the cerebral processing of person-related information in perceptual and neural voice representations. Results indicate a cerebral architecture of voice cognition sharing many similarities with the cerebral organization of face processing, with the main types of information in voices (identity, affect, speech) processed in interacting, but partly dissociable functional pathways.

Neural networks underlying vocal behavior in primates

Steffen Hage[1]
[1]CIN, University of Tübingen

The human language faculty vastly outperforms any primate vocal communication system in scope and flexibility, with seemingly no counterpart in the animal kingdom, even among hominids. Vocalizations of nonhuman primates are innate, stereotypic, and were thought to be almost exclusively uttered affectively. Humans, on the other hand, learn speech sounds, use them flexibly in combinatorial symbol systems, and can volitionally control their utterances. However, even if the speech and language system in humans is categorically different from the vocal motor system of non-human primates, the theory of evolution postulates pre-adaptations in the primate lineage, no matter how exiguous they might be. One such critical precursor is volitional control of vocal utterances. Another pre-adaptation that is deemed to be crucial for the development of a flexible communicative system, such as human speech, is the ability to modulate vocal patterns in response to external acoustical stimuli. In my talk, I will give an overview on recent studies suggesting that monkeys are able to control their vocal output in a goal-directed way and that this behavior is encoded by prefrontal brain structures that are directly homologous to human cortical structures that are critical for speech production. In addition, I will show that this prefrontal network in monkeys gets direct input from auditory side suggesting that it is well positioned to combine higher order auditory processing with cognitive control of vocal motor output. Finally, I will give insights into recent studies that indicate a potential role of auditory feedback on vocal development in marmoset monkeys.

Lips and tongue are close to ears: Motor contribution to speech perception

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Speaking and listening are intrinsically linked. However, does the speech motor system play a role in speech perception? If so, at what manners (how) and circumstances (when) the motor system contributes, and whether its function could be modulated by age and experience (plasticity)? In this talk, I will present evidence from human fMRI studies revealing that the articulatory prediction-based encoding in the speech motor system excels the auditory encoding in auditory cortex in discriminating syllables masked by noise, and the auditory-motor integration facilitates speech perception only when the speech signals are degraded and uncertain. Moreover, I will show that this motor mechanism is maintained and becomes more critical in compensating dedifferentiated speech representations and declined speech in noise perception in older listeners. Finally, I will demonstrate that long-term musical training benefits speech in noise perception, which may partially relate to finer phonological representations in and stronger functional connectivity between auditory and speech motor regions in driving speech recognition. The idea that musical training could improve speech in noise perception by enhancing auditory-motor integration is intriguing, with potential applications in alleviating speech perception difficulties in aging populations and hearing disorders.

Putting sounds in context

Jennifer Linden[1]

[1]University College London

The linearly-weighted receptive field has been used to describe central auditory responses to complex stimuli for decades, and one or more linearly-weighted fields also lie at the heart of more recent linear-nonlinear (LN) approaches to analysis of neuronal responses to complex sounds. However, the crucial assumption of linear weighting---that the sensitivity of the neuron to a local element of the stimulus is independent of the rest of the stimulus---is challenged by many reports of nonlinear combination sensitivity in the central auditory system. Such nonlinearities include forward suppression of the response to the second tone in a pair and more complex combination effects for spectrally offset tone pairs. How do these and perhaps other contextual nonlinearities combine over frequency and time to shape neuronal responses to sounds more complex than tone pairs? In this talk, I will describe the impact of local acoustic context on auditory cortical and thalamic responses to complex sounds, as determined through experiments that involved recording neuronal responses to spectrotemporally rich dynamic random chord stimuli in two subdivisions of the mouse auditory thalamus and two auditory cortical fields. We found that in both auditory cortex and thalamus, elements of a complex sound modulate neuronal responsiveness more effectively when they coincide with sounds at distant frequencies, and less effectively when they are preceded by sounds at similar frequencies. This input-specific gain modulation is evident in awake as well as anaesthetised animals. Such local-context-driven lability in receptive fields may be a widespread motif in sensory processing.

What can we learn from statistical models of auditory cortex neurons?

Jan Schnupp[1], Nicol Harper[2], Benjamin Willmore[2], Neil Rabinowitz[3], Andrew King[2]
[1]City University of Hong Kong, [2]University of Oxford, [3]Google

Understanding the input-output transformations of neurons in the auditory system is perhaps the key problem in auditory neuroscience. Given the stochastic nature of neural discharges, this problem is usually framed as a statistical one: one attempts to predict the firing probability , or equivalently, the average firing rate, for arbitrary inputs. Attempts to characterize input-output functions for early stages of the auditory pathway go back half a century, with deBoer et al characterizing auditory nerve fiber responses with reverse correlation as long ago as 1967. However, such methods usually only "measure the linear part" of a neuron's input-output function, and since even early parts of the auditory system contain substantial and well known non-linearities, applying this type of approach to cortical neurons was thought to be unlikely to be useful until a paper by deCharms et al (Science 1998) alerted the community to the feasibility of estimating spectro-temporal receptive fields (STRFs) of cortical neurons. Since then STRF models of cortical neurons, have been eagerly adopted and developed further by some groups, and studiously ignored by others. Recent years have seen useful extensions to a purely linear framework with so called linear-nonlinear (LN), or even non-linear-linear-nonlinear (NLN) models, which contain linear STRFs sandwiched between non-linearites modelled on known large-scale physiological non-linearities. In my talk I will use examples from work that I have been involved in over the last 20 years to illustrate both the strengths and the limitations of STRF approaches, briefly discuss conceptual and methodological background, and I will provide examples of how STRF and derived models have contributed to our understanding of such diverse topics as binaural spatial processing or adaptation to changing auditory contrast or to background noise in auditory cortex.

From learning to memory: New insights from auditory neuroethology

Robert Liu[1]
[1]Emory University

How auditory memories of behaviorally relevant sounds are formed, where in the brain their long-term traces lie, and what function these neural traces serve in driving responses are long-standing questions in the field of auditory neuroscience. Many studies have demonstrated that auditory cortex contains an altered neural trace of sounds that become behaviorally relevant, but the details of the changes observed are often dependent on the specifics of the learning task. In this talk, I will discuss recent work revealing previously unappreciated mechanisms using ethological behaviors to model adult auditory learning of both positive and negative valence sounds. First, while studies using pure tones to drive auditory cortical plasticity with operant conditioning have long reported tonotopic map expansion, a natural sound learning paradigm in mice that begin recognizing the appetitive meaning of natural ultrasonic vocalizations does not, and instead induces inhibitory plasticity at a population level. Second, using auditory fear conditioning to learn the aversive meaning of a tone, we report the unexpected finding that auditory cortical activity during a time window after fear learning is necessary for consolidating the sound's meaning. Suring the post-experience period, components of the auditory cortical extracellular matrix's perineuronal nets (PNNs) are dynamically increased, seemingly implying a brake on plasticity, given work on PNNs during the closure of sensory critical periods in development. We speculate that this temporally delayed upregulation of PNNs helps protect recent sound memories that are still consolidating from interference by other sound experiences. In fact, removing auditory cortical PNNs results in a deficit in sound cue consolidation. These ethologically motivated studies have thus helped reveal detailed electrophysiological and molecular mechanisms by which auditory cortical plasticity during learning contributes to auditory memory.

How the human brain detects, represents and uses patterns in sound sequences

Maria Chait[1]
[1]UCL

I will present ongoing work in my lab using brain imaging (EEG, MEG and fMRI), behavioural and eye-tracking experimentation to reveal how human listeners discover patterns and statistical regularities in sound sequences. Sensitivity to patterns is fundamental to sensory processing, in particular in the auditory system, and a major component of the influential 'predictive coding' theory of brain function. Supported by growing experimental evidence, the 'predictive coding' framework suggests that perception is driven by a mechanism of inference, based on an internal model of the signal source. However, a key element of this theory - the process through which the brain acquires this model, and its neural underpinnings - remains poorly understood. Our experiments focus on this missing link. The research approach, based on measuring behavioural and brain responses to rapid tone-pip sequences governed by specifically controlled rules along a variety of feature dimensions enables us to address questions related to (1) how the brain discovers patterns in sound sequences, (2) which neural mechanisms are involved, (3) to what degree the process is automatic or susceptible to attentional state and behavioural goals of the listener.

A cortico-collicular amplification mechanism for gap detection

Mike Wehr[1]
[1]University of Oregon

A key function of the auditory system is to detect events in the environment, which are signaled by fluctuations in acoustic input. Events can be signaled by either increases or decreases in sound intensity, to which the auditory system is exquisitely sensitive. Lesions or optogenetic suppression of auditory cortex have no effect on the detection of sound increments (such as noise bursts), but strongly impair the detection of sound decrements (such as brief gaps in noise). Why is auditory cortex necessary for gap detection, and what's special about brief gaps in particular? Here we identified a collicular-cortico-collicular gap detection circuit in which auditory cortex amplifies neural responses to brief gaps before sending this information back to inferior colliculus to impact behavior. Both noise bursts and gaps consist of sound onsets and offsets. These evoke off-responses and on-responses in cortical neurons that temporally overlap for brief gaps, but not long gaps. Because information about sound offsets and onsets ascend through separate synaptic channels to cortex, these responses sum independently, amplifying cortical gap responses. As a result, responses in cortical neurons were specifically enhanced for brief gaps, whereas IC neurons preferred longer gaps. Optogenetic suppression of auditory cortex revealed that this enhanced cortical representation in turn projects back to IC and amplifies collicular responses to brief gaps. Thus gap responses are amplified in auditory cortex, and impact gap detection behavior through downstream corticofugal effects on gap processing in IC.

Incidental auditory category learning

Lori Holt[1]
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Categorization is a powerful cognitive process that supports the recognition, differentiation, and interpretation of objects and events. Although not as well-studied as visual category learning, auditory category learning has a prominent role in speech perception where listeners must acquire mappings among multiple spectrotemporal acoustic dimensions and native-language linguistic units. Ultimately, auditory category learning allows experienced listeners to extract meaning from complex sensory signals and to generalize learning to novel sounds and contexts. A substantial amount has been learned about the cortical locus of learning-related change in auditory and speech categorization. Yet, little is known about the learning mechanisms and associated brain systems that drive changes in auditory categorization behavior and cortical representation. At least under conditions of explicit training with performance feedback, the striatum is a likely contributor to auditory category learning. But, much less is known about whether the striatum is engaged in auditory category learning under more ecologically valid learning conditions that involve multiple forms of sensory input and limited explicit feedback like the conditions that characterize speech category learning. I will describe research in which adults play a customized videogame during which they learn auditory categories incidentally, through the categories' utility in supporting successful videogame navigation. This incidental training supports both speech and nonspeech auditory category learning that generalizes to novel exemplars and is predictive of later overt category labeling accuracy. fMRI results implicate striatal recruitment during the learning process and demonstrate that striatal engagement relates closely to behavioral learning outcomes. In sum, the striatum is involved in learning auditory categories in rich, multimodal environments with limited explicit feedback.

Emergence of category percepts in auditory cortex

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Basic perceptual attributes of sound such as pitch, loudness, and location, are extracted early along the auditory pathway. However, as neuronal activity propagates beyond A1 to higher auditory fields, and to frontal cortical regions, it gradually undergoes a fundamental transformation from representing acoustic features of sound to encoding more abstract properties such as sound category and its behavioral meaning within the context of the auditory task being performed. We shall describe neurophysiological evidence for this process, and its manifestation through engagement with key cognitive functions of attention, reward, learning, memory and decision-making.

TT-L-1 Egocentric and allocentric representations in auditory cortex

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Sound location is a critical aspect of auditory perception and must be computed from binaural cues. It has therefore been assumed that spatial tuning reflects egocentric sensitivity to sound source location relative to the head rather than allocentric tuning to sound locations in the world. However, the coordinate frame in which neurons define space is ambiguous in head-fixed subjects in which head-centered and world-centered sound source locations are in fixed alignment. This ambiguity can be resolved in freely moving subjects when head and world coordinate frames are dissociated. Here we recorded neural activity and head position in freely moving ferrets actively foraging within a semi-circular speaker ring (7 speakers at 30° intervals). We recorded 92 spatially tuned units for which we compared tuning to sound location relative to the head and in the world using traditional measures of modulation depth and also general linear modelling. We recorded 72/92 egocentric units that represented sound location relative to the head, and for which we could measure super-resolution (5°) panoramic (360°) azimuthal tuning curves. We also recorded 19/92 allocentric units in which sound location was represented in a world-centered coordinate frame. We used changes in head position to explore the influence of sound source distance, finding that modulation depth increased significantly with distance for egocentric ($p=0.03$) but not allocentric units ($p>0.1$). We also studied how head-movement speed modulated neural activity, finding that speed enhanced baseline activity of spatially tuned units ($p<0.001$), that in 74/92 units sound-evoked activity was modulated by movement speed, and that speed significantly affected modulation depth in egocentric ($p<0.001$) and allocentric units ($p<0.001$). Our findings show that auditory cortex represents egocentric and allocentric sound source location and that both sound source distance and observer movement affect cortical and spatial processing.

TT-D-2 Mechanisms of movement-related changes in auditory detection thresholds

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Our ability to distinguish sensory stimuli that arise from the external environment from those that arise from our own movements is critical for our survival. How the brain makes this distinction is not clear. With respect to audition, studies in humans and other animals have demonstrated that self-generated vocalizations as well as other movements suppress auditory cortical responses to acoustic stimuli relative to responses to the same stimuli measured at rest. Recent work in the mouse has shown that a subset of motor cortical neurons sends axons to the auditory cortex, where they synapse on inhibitory neurons that suppress the activity of excitatory cells. An influential but largely untested idea is that this cortical suppression works to minimize responses to predictable acoustic consequences of movements, while enhancing sensitivity to novel stimuli. How this cortical suppression influences auditory perception and whether this suppression functions predictively, as widely theorized, remain unknown. To explore

these issues, we used operant methods to train head-fixed mice to lick in response to tone pips of varying intensities while at rest or running on a quiet treadmill. Using this approach, we observed that: 1) the overall threshold for auditory detection is elevated during movement compared to rest, 2) inactivating the auditory cortex elevates tone detection thresholds, 3) optogenetic activation of motor cortical terminals in the auditory cortex of resting mice increases detection thresholds in a manner similar to movement, and, 4) following experience with predictable movement-related auditory feedback, the movement-related elevation of auditory threshold is specific to predicted sounds. These findings support a model in which motor cortical inputs to the auditory cortex function as part of a mechanism for selectively suppressing predictable acoustic consequences of movement.

TT-B-3 Mapping functional and anatomical connections within the human auditory pathway with ultra-high field MRI

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Investigating the anatomical and functional properties of the sub-cortical auditory pathway in living humans using magnetic resonance imaging (MRI) is challenging. The size of sub-cortical structures requires high spatial resolution but signal to noise is limited by their anatomical location. Therefore, previous studies have simultaneously investigated cortical and subcortical locations only at low spatial resolution. Here we map the anatomical and functional architecture of the human auditory pathway using 7 Tesla MRI. We acquired functional (rest and task based; 1.1 mm isotropic covering coronally the auditory pathway), diffusion weighted (1.05 mm isotropic) and anatomical (0.7 mm isotropic) data and present preliminary results on the auditory connectivity as determined by resting state fMRI and diffusion tractography. In each individual, we defined sub-cortical auditory structures (cochlear nucleus, superior olivary complex, inferior colliculus, medial geniculate body) using task based functional responses and parcellated the auditory cortex in nine patches using anatomical landmarks. All regions were used to compute functional and anatomical seed-based connectivity and connectograms. Resting state connectivity highlighted stronger connections between sub-cortical regions following the hierarchy of the pathway but also showed connectivity across the hemi-line between homologous regions. This contralateral pattern was reduced in diffusion data. Sub-cortical to cortical connections highlighted a strong hub-like role of the medial geniculate body and its connectivity to Heschl's gyrus. Leveraging the high spatial resolution of this dataset we will investigate connectivity at the finer scale of tonotopic maps, the ability of diffusion MRI to aid in parcellating the medial geniculate body and whether the information of subcortical anatomical connectivity can improve our understanding of the cortical architecture.

TT-F-4 Auditory and visual sequence learning in humans and monkeys

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Language flexibly supports the human ability to communicate using different sensory modalities. Moreover, syntactic operations engage certain overlapping regions in the human brain during reading in the visual modality and listening to language in the auditory domain. Although it has been argued that nonhuman primate communication is inherently multisensory, there are few direct comparisons of human and other primate abilities across sensory modalities. Artificial Grammar Learning (AGL) tasks (also known as statistical learning) can emulate ordering relationships between words in a sentence.

However, comparative work with such paradigms has primarily investigated sequence learning in a single modality. We used an AGL paradigm to evaluate how humans and macaque monkeys respond to identically structured sequences of non-linguistic auditory or visual stimuli. In both modalities, the two species gave similar response patterns in the visual and auditory domains, indicating that the sequences are processed comparably across the sensory modalities. We conducted an fMRI experiment using the same auditory and visual sequences in humans and an equivalent macaque fMRI experiment is underway. Multi-voxel pattern analysis of the human fMRI results, using Representational Similarity Analysis (RSA) investigated brain responses in auditory cortex and other additional regions of the perisylvian network. The results show that a number of perisylvian regions in the human brain respond to aspects of the sequences' ordering relationships in both modalities. This included the angular gyrus and areas 44/45 and the frontal operculum in frontal cortex. The results provide evidence that human sequence processing abilities stem from an evolutionarily conserved capacity for multisensory sequence processing. The findings set the stage for neurobiological studies to comparatively assess the multisensory nature of these sequence processing operations in animal models.

TT-D-5 Stability and plasticity of sensory representation in the auditory cortex

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In a constantly changing world, sensory systems are required to balance between providing a stable representation of the environment, and adapting to changes in sensory contingencies so as to allow the animal to effectively respond to behaviorally relevant cues. We sought to characterize these changes in the mouse auditory system, focusing on primary auditory cortex (A1) and the anterior auditory field (AAF). We used chronic 2-photon imaging of the calcium sensor GCaMP6s to record responses of defined neural populations in L2/3 of A1 and AAF in awake animals before, during and after perceptual learning. We trained adult mice to discriminate between two auditory stimuli that varied along a continuous axis of similarity, from easy to difficult. Training was performed in an automated cage (the 'Educage') that allowed us to continuously train groups of mice in this paradigm. We compared and quantified changes in the response properties of neuronal ensembles as mice learned the progressively difficult discrimination tasks. Sensory responses were different in the awake brain compared to the same cells in isoflurane-anesthetized animals, and were significantly more stable across days in the awake brain. These data reveal the basal fluctuations of stimulus representation under control conditions and suggest a stable substrate, which is amenable to change. Our results show that easy discrimination tasks cause little change in sensory coding. However, initial analysis suggests that as the animal reaches its perceptual limits, significant changes can be induced in neuronal responses to the same stimuli. These results suggest that cortical plasticity can act as a permissive mechanism for perceptual learning.

TT-L-6 Altered adaptation to sound-level statistics in the auditory cortex of older adult humans

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Optimal perception requires efficient and adaptive neural processing of the sensory environment. For example, neurons adapt to statistical properties (e.g., mean, variance) of acoustic feature distributions, which enhances sensitivity to sounds that are most likely to occur in the environment. However, adaptation to stimulus statistics has mainly been investigated in young nonhuman animals. We know very little about how human neural responses adapt to stimulus statistical distributions and how aging affects adaptation to stimulus statistics. We used magnetoencephalography to study how exposure to different distributions of sound levels affected adaptation in auditory cortex of younger (mean: 25 years; N=19) and older adults (mean: 64 years; N=20). Adaptation was quantified as a reduced neural response magnitude and response modulation to identical sounds depending on the acoustic context. Participants passively listened to two sound-level distributions: one distribution had a modal sound level of 15 dB SL (sensation level), the other one had a modal sound level of 45 dB SL. In a control block with long inter-stimulus intervals, allowing neural populations to recover completely from adaptation, neural response magnitudes were comparable between younger and older adults. Critically, we observed clear evidence for adaptation to sound-level stimulus statistics in both age groups, but adaptation to stimulus statistics was incomplete for older compared to younger people. That is, neural responses continued to be modulated by sound levels for older adults under conditions where responses should have been fully adapted. The lack of full adaptation to the statistics of the sensory environment may be a physiological mechanism for the known difficulty older adults have with filtering out irrelevant sensory information, and this may also be related to loudness recruitment.

TT-D-7 A comparison of marmoset frontal cortex neuron responses to acoustic stimuli in multiple behavioral contexts

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Primate vocal communication is characterized by the production and perception of vocalizations within the context of active social behaviors. Within this complex system, what is communicated by a vocalization is heavily dependent on the immediate social context in which it occurs. However, much of what is known about the neural basis of primate communication comes from traditional studies involving subjects that are either passively listening or trained to respond to vocalizations with a conditioned behavioral response. Because of the active nature of communication, each of these more conventional approaches divorces the signal from the core context in which it naturally occurs. Here we sought to test this critical issue by recording the responses of frontal cortex neurons in marmosets across multiple behavioral contexts. Specifically, we presented the same vocalizations (phee calls, twitters) and a variety of white noise stimuli to marmosets while they were head-fixed and freely-moving using identical stimulus presentation protocol. During each of these test sessions, we also recorded the same neurons while subjects engaged in their natural antiphonal calling behavior, which involves the reciprocal exchange of phee calls. Preliminary analyses revealed that (1) white noise elicited the most consistent and robust responses across all test stimuli, (2) only half of neurons responsive to an acoustic stimulus in the head-fixed condition exhibited a similar response to the same stimulus in the freely-moving condition and (3) phee calls elicited the weakest responses of all stimuli in all conditions. These findings suggest that neural responses under head-fixed, passively listening conditions may not be predictive of more natural contexts. We are currently examining a broader set of stimuli in order to test the hypothesis that distinct neural processes may underlie vocal signal processing during natural, active communication and these other behavioral contexts.

TT-J-8 Auditory scene segregation can be impaired under high visual load

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Scene segregation has frequently been shown to occur in the absence of explicitly directed attention, leading to suggestions that this is an automatic auditory process. However, depending on the spectro-temporal composition of the sounds, separating an object out from an ongoing scene can potentially have very high computational demands. It remains to be seen whether very high load in an attended task could deplete processing resources to the point where an unattended auditory scene would not be automatically segregated. Here, we looked for characteristic neural responses to auditory objects within scenes while attention was actively directed towards demanding visual tasks. Auditory signals ('stochastic figure-ground': SFG; Teki et al., 2016) were comprised of a sequence of brief broadband chords containing random pure tone components that varied from one chord to another. We used very short (200ms overall; 25ms chords) stimuli, 50% of which contained repeated frequency components which are perceived as 'figures' popping out of a stochastic 'ground'. Passive MEG responses to the scenes were recorded during active visual search (where 200ms visual stimuli were presented at precisely the same time as the auditory scenes) of both low and high visual perceptual load. The evoked responses and source estimations both demonstrated a neural signature for segregation under low visual load which was not apparent under high load. These data suggest that the process of auditory scene segregation can be disrupted when a concurrent, active visual task places a sufficiently high demand on processing resources. We conclude that while scene segregation is carried out by default when there are resources available, it is not truly 'automatic'. References: Teki, S., Barascud, N., Picard, S., Payne, C., Griffiths, T. D., & Chait, M. (2016). Cereb Cortex, 26(9), 3669-3680.

TT-I-9 Auditory cortex interneuron development requires cadherins operating hair-cell mechanoelectrical transduction

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Many genetic forms of congenital deafness affect the sound reception antenna of cochlear sensory cells, the hair bundle. Auditory cortex (AC) maturation, which is jeopardized by sensory deprivation in deaf children, should be restored by early prosthetic intervention unless there are intrinsic AC defects, a possibility as yet unexplored. We show here that many γ-aminobutyric acid (GABA)ergic interneuron precursors, from their generation in the medial ganglionic eminence up to their settlement in the AC, express two cadherin-related (cdhr) proteins, cdhr23 and cdhr15, that form various types of hair bundle links, including tip links. Mutant mice lacking either protein had smaller numbers of parvalbumin interneurons specifically in the AC, and displayed audiogenic reflex seizures. Cdhr15- and cdhr23-expressing interneuron precursors in Cdhr23-/- and Cdhr15-/- mouse embryos, respectively, failed to enter the embryonic cortex and were scattered throughout the subpallium, consistent with the cell polarity abnormalities observed in vitro. In the absence of adhesion G protein-coupled receptor V1 (adgrv1), another hair bundle link protein, the entry of cdhr23- and cdhr15-expressing interneuron precursors into the embryonic cortex was also impaired. Our results demonstrate that a population of newborn interneurons is endowed with specific cdhr proteins, necessary for these cells to reach the developing AC. We suggest that an "early adhesion code" targets populations of interneuron precursors to restricted neocortical regions belonging to the same functional area. These findings, revealing major intrinsic defects of the AC in deafness forms previously thought to be exclusively of cochlear origin, open up new perspectives for patient rehabilitation and cortical therapies.

TT-G-10Microstructural development of human primary and nonprimary auditory cortex during the perinatal period

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Primary and nonprimary cerebral cortex mature along different timescales. Variation in metrics of water diffusion, obtained from diffusion-weighted magnetic resonance imaging (MRI), has proven useful for tracking microstructural maturation of cortex and underlying subplate/white matter tissue during early human brain development in vivo. Here we used diffusion MRI to characterize the maturational timeline of primary (pAC) and nonprimary auditory cortex (nAC) microstructure during the perinatal period. We analyzed longitudinal data from 90 infants born very preterm (<30 weeks gestation) who each underwent diffusion MRI up to four times between 26 and 42 weeks postmenstrual age (the equivalent of the third trimester of gestation). Values for diffusion metrics of fractional anisotropy and mean, axial, and radial diffusivity were obtained from regions of interest placed in the cortical plate and adjacent subplate/white matter tissue located along the length of Heschl's gyrus (HG). Our analysis revealed differing rates of maturation along the axis of HG as cortex transitions from pAC to nAC. While pAC was further advanced along the developmental timeline at each timepoint (as measured by diffusion parameters), nAC showed much larger changes from 26 to 42 weeks postmenstrual age than did pAC. Disrupted perinatal maturation of nAC, but not pAC, was associated with poorer language performance at age 2 years. Our data provide in vivo demonstration of an important facet of human cortical maturation: primary sensory cortex develops earlier than nonprimary cortex. We were able to distinguish between pAC and nAC as early as 28 weeks postmenstrual age, a time at which the sulcal boundaries of HG are just beginning to appear. Our results indicate nAC makes more rapid changes during the perinatal period than pAC, which may render it more vulnerable to disruption and/or environmental influences.

TT-I-11 GABAA receptor activation during developmental hearing loss leads to a broad recovery of cellular properties in adults

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Introduction: Sensory deprivation can induce profound changes in central auditory processing during developmental critical periods (CPs). Here, we used a novel recombinant adeno-associated virus (rAAV) that restricts channelrhodopsin expression to telencephalic GABAergic interneurons. We used an optogenetics approach with reversible hearing loss to identify separate CPs of recovery for ACx GABAA and GABAB receptor function. We then administered either a GABAA receptor α subunit-specific nonbenzodiazepine (zolpidem) or a selective GABA reuptake inhibitor (SGRI) throughout the period of hearing loss. Methods: Bilateral earplugs were inserted in gerbils (Meriones unguiculatus) on postnatal day 11, and were subsequently removed at successively later ages (P13, P17, or P18). On P48, ACx was injected with rAAV-mDlx-ChR2-mCherry (50 nl). Adult thalamocortical brain slices were generated and whole-cell current- clamp recordings were obtained from unlabeled L2/3 pyramidal cells. Inhibitory postsynaptic potentials (IPSPs) were evoked by stimulating with 1 ms pulses of blue light (470 nm). Zolpidem and SGRI (10mg/kg) were administered subcutaneously throughout the duration of hearing loss (P11 to 18). Results: Light stimulation reliably evoked IPSPs that were composed of a short latency GABAA and a long latency GABAB receptor-mediated component. When hearing loss was reversed at

P17, only GABAAergic IPSPs were smaller in adults. In contrast, when hearing loss was reversed at P18, then both GABAA, and GABAB receptor-mediated IPSPs were significantly diminished. The administration of either zolpidem or SGRI throughout the transient period of hearing loss led to the complete recovery of GABAergic receptor and intrinsic properties in adults. Conclusion: Our results demonstrate that target activation of GABAA receptors with either of 2 FDA-approved agents leads to the recovery of a broad range of cellular properties.

TT-I-12 Visualizing homeostatic normalization in the output of long-range auditory subcortical projection neurons following a sudden drop in peripheral afferent drive

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Following a sudden loss of peripheral input, cortical inhibition plummets and never fully recovers. Presumably, cortical disinhibition helps to compensate for the drop in afferent drive and restores the net output from the cortical column to its homeostatic set point. To test this directly, we tracked daily changes in layer 5 (L5) projection neurons in the auditory cortex before and after a selective loss of auditory nerve afferent synapses. The excitability of L5 subcortical projection neurons was measured directly by expressing a genetically encoded calcium indicator, GCaMP6s, and directly visualizing sound-evoked signals from L5 cortical axons on the dorsal cap of the inferior colliculus in awake, head-fixed adult mice. After several days of imaging stable sound-evoked L5 corticocollicular (CCol) activity in a baseline state, mice were exposed to moderate noise that caused only a temporary shift in cochlear and brainstem thresholds but a permanent loss of auditory nerve afferent synapses. We found that the auditory gain of CCol responses dropped the day after noise exposure but then spiked, exceeding baseline levels for several days before returning to baseline. These findings reveal short-term dynamics in the auditory corticofugal pathway following cochlear synaptopathy and suggest that local circuit changes in the auditory cortex might allow corticofugal projection neurons to stabilize their output in the face of large swings in afferent drive. Our ongoing work examines the local circuit mechanisms that support this homeostatic plasticity.

TT-E-13 Role of auditory cortex in self-monitoring and feedback-dependent vocal control

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Speech is a sensory-motor process involving auditory self-monitoring to control vocal production and ensure accurate communication. The ability to monitor auditory feedback during vocal production allows individuals to quickly adjust speech and compensate for perceived changes in vocal output, a behavior shared by many animal species. Despite the importance of this mechanism, the underlying neural processes are not known. Previous studies have demonstrated that auditory cortex neurons are suppressed during vocal production, while simultaneously maintaining their sensitivity to externally-perturbed auditory feedback. However, the role of such neural activities in feedback-dependant vocal control remain unknown. We investigated the role of auditory cortical activity during vocal self-monitoring and feedback-dependant vocal control in marmoset monkeys. We used implanted electrode arrays to record neural responses during self-initiated vocal production while simultaneously altering vocal feedback. We found that, when presented with real-time frequency-shifted feedback, marmosets will compensate by rapidly changing the acoustics of their ongoing vocalizations. This vocal compensation was predicted by auditory cortical activity evoked by altered feedback. To further determine a causal role for the auditory cortex during vocalization, we used electrical microstimulation during vocal production and found rapid changes in the produced vocalizations. These results demonstrate the function of the auditory cortex in vocal self-monitoring, and suggest a causal role in vocal motor control and feedback-dependent vocal behavior. This work was supported by NIH/NIDCD Grant K08-DC014299.

TT-D-14Obligatory and facultative brain regions for voice-identity recognition

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Voice-identity recognition is an important skill for social interactions. It is by-and-large unknown how this skill is accomplished by the human brain. In the past decade a wealth of neuroimaging studies have shown that a central structure involved in voice-identity recognition is the right temporal lobe. However, neuropsychological case studies reported that voice-identity recognition deficits in patients with brain lesions are associated with lesions in the right inferior parietal lobe. The aim of the present study was to work towards resolving the discrepancy between neuroimaging studies and patient lesion case reports to get a better understanding, which structures in the human brain are critical for voice-identity recognition. To do this, we performed a voxel-based lesion symptom mapping (VLSM) study on 58 patients with unilateral focal brain lesions. The study included a comprehensive behavioural test battery, neuropsychological assessment and high-resolution structural brain images. The VLSM analysis revealed three key findings. (i) We identified a strong association between lesions in the temporal and right inferior parietal lobe and voice-identity recognition deficits. (ii) Of these two structures, only the right temporal lobe remained significant when we controlled for face-recognition performance indicating a high voice sensitivity of the right temporal lobe. The right inferior parietal lobe was particularly involved in tasks, which required association of voice and face information. (iii) Deficits in recognising newly-learned and familiar voices were associated with distinct brain lesions. With our results we supported a central assumption of the current voice-identity processing model: We provided evidence that the right temporal lobe is an obligatory structure for successful voice-identity recognition. In contrast, the inferior parietal lobe rather represents a facultative component of voice-identity recognition.

TT-E-15 Behavioral relevance enhances responses at the offset of natural vocalizations in auditory cortex

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Sound stimuli elicit different types of spiking responses in the awake auditory cortex, ranging from transient onsets (Heil, J Neurophysiol 1997) and sustained firing (Wang et al, Nature 2005) to offset responses (Qin et al, J Neurophysiol 2007). Detailed studies of what sound features are encoded by these response types have mostly used artificial stimuli with no inherent behavioral relevance for animals. Here we show using a communication sound learning paradigm in mice that increasing a sound category's behavioral relevance particularly enhances responses that start after sound offset, and these responses depend on a sound's "pitch" trajectory. Pup isolation ultrasonic vocalizations (USV), which are meaningful to maternal but not non-maternal mice, are single-frequency whistles whose pitch trajectories are naturally variable. These trajectories are stereotyped and distinct from adult USVs, which are spectrally similar but have different stereotyped pitch trajectories - a fact we can statistically quantify by modeling USVs from our library (Liu et al, JASA 2003) with sinusoidal plus linear FM. Using awake, head-fixed single-unit electrophysiology, we find that the strength of offset responses correlates positively ($p<0.01$) with the statistical likelihood of a pitch trajectory to be found in natural pup USVs, and negatively ($p<0.01$) with adult USV likelihood. Maternal experience increases ($p<0.001$) the proportion of neurons with USV-offset responses from 42% in non-maternal (n=132) to 63% in maternal (n=158) mice, with the greatest increase occurring in putative thick-spike pyramidal neurons ($p<0.0001$). Preliminarily, tuning to FM parameters systematically varied around natural USVs also changes with experience, particularly in noncore auditory cortex. Together, these results point to a previously unappreciated plasticity in auditory cortical offset responses, which acquire greater sensitivity to the complex pitch trajectories in a learned sound category.

TT-D-16 Single-neuron correlates of spatial attention and choice in auditory and prefrontal cortex

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Auditory spatial attention describes our effortless ability to listen to sound from one location while suppressing distracting sounds from other locations. Two key areas implicated in this ability are auditory cortex and prefrontal cortex, but a detailed understanding of how sound is spatially filtered has been hampered by the lack of a robust animal model, particularly one that shares key similarities with humans. To address this, we have developed a novel spatial auditory selective attention task for macaques, based closely on human directed listening paradigms. In this task, a macaque monkey is cued to a particular side and must report the presence of a difficult-to-detect auditory target (embedded in noise) only if it appears on the cued side. If it appears on the uncued side, he must ignore it. We collected single neuron data from prefrontal cortex (caudal principal sulcus; n=948) and caudal auditory cortex (primarily A1; n=847) in two monkeys during this task. In both areas, direction of cued side significantly affected responses in about 20% of the neurons. A comparison of patterns between PFC and AC indicated that AC was earlier than PFC in signaling the sensory stimulus (ipsi/contra), but PFC was earlier than AC in signaling the decision made (release/ignore). We applied a classification approach on firing rates of the responsive populations to analyze patterns of firing rates related to error (e.g. misses) vs correct trials, This indicated that the first location to exhibit patterns of activity that classified significantly lower than correct was in AC during the masking noise period. Thus, at least some errors are due to an inability to suppress noise at the level of sensory cortex. These results add insight into the cortical dynamics of auditory decision making during effortful listening.

TT-K-17 Monkeys share with humans the neurophysiological basis for encoding sound peridiocities as captured by the frequency-following response (FFR)

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Brain sensitivity to the sustained and periodic components of sounds is captured by the FFR, an auditory evoked-potential that reflects synchronous phase-locked activity elicited by the periodic acoustical features. FFR is malleable by experience and has been used as a biological marker of the stability of sound processing across a variety of pathologies revealing an intricate coupling between auditory processing and cognitive abilities such as beat perception or literacy. Despite clinical and empirical interest, the FFR neuronal basis remain poorly understood and there is a lack of cross-species comparison studies. Here, we performed electroencephalographic recordings in 15 humans and two rhesus monkeys who passively listened a /da/ syllable, delivered via free-field with alternating polarities at a rate of 11.1 Hz and 85 dB SPL. Human FFR response was consistent across subjects and similar to the one described in previous studies. Importantly, FFR potential recorded in awake macaque using the same stimulation and recording set-up exhibited all the transient and sustain elements observed in human FFR. In both species, FFR response consisted of onset components labeled as the V-A complex analogous to the click-evoked V-Vn complex. Likewise, transient elements - i.e. peak C and O - corresponding to the beginning and end of voicing were observed. Finally, the three periodic peaks that correspond to neuronal phase-locking to the fundamental frequency and harmonics of sound were clearly elicited in both species and labeled as D-F. Results reveal the activation of analogous brain areas in both species and indicate that monkey share with humans the neuronal mechanisms to encode sound periodicities as revealed by the FFR potential. This is the first time that a non-human primate FFR is successfully recorded on the scalp allowing to perform translational research to assess the neuronal basis of sound processing and its plasticity to behavioral interventions.

TT-D-18Mapping the cortical representations of statistical changes from auditory cortices to frontal cortex

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Natural sounds such as wind or rain are characterized by the statistical occurrence of their constituents. Despites their complexity, listeners can readily detect changes in continuous acoustic streams. However, the neural basis of the extraction of relevant information in complex streams for goal-directed behavior is currently not well understood. As a model for change detection in complex auditory environments, we designed spectrotemporally broad acoustic textures whose statistics change at a random time. Ferrets were trained to detect these changes within continuous sound. Hence, they are faced with the dual-task of estimating the baseline statistics and detecting a potential change in those statistics at any moment, mimicking real-life challenges. To characterize the extraction of relevant sensory information performed between sensory cortices and frontal areas, we performed electrophysiological recordings in the primary auditory cortex (A1), secondary auditory cortex (PEG) and dorso-lateral frontal cortex (dlFC) of the behaving ferret. A1 neurons exhibited strong onset responses and reduced change-related discharges, whereas dlFC neurons presented an enhanced response to change-related events only during behavior, possibly reflecting accumulation of sensory evidence. These area-specific responses to the behaviorally relevant acoustic event are also reflected in the LFP modulations which showed enhanced responses to changes, although not behaviorally gated until the frontal cortex. All together, this suggests a behavior-dependent mechanism of sensory extraction and amplification of task-relevant event.

TT-G-19Parallel streams define the temporal dynamics of speech processing across human auditory cortex

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To derive meaning from speech, we must extract multiple dimensions of concurrent information from incoming speech signals, including phonetic and prosodic cues. Equally important is the detection of acoustic cues that give structure and context to the information we hear, such as sentence boundaries. How the brain organizes this information processing is unknown. Here, using data-driven computational methods on an extensive set of high-density intracranial recordings from 27 patients, we reveal a large-scale partitioning of the entire human speech cortex (including primary auditory cortex, belt, and parabelt areas) into two spatially distinct regions that detect important cues for parsing natural speech. These caudal (Zone 1) and rostral (Zone 2) regions work in parallel to detect onsets and prosodic information, respectively, within naturally spoken sentences. We then analyzed the spectrotemporal and phonetic feature selectivity of electrodes within these zones using linear encoding models. Rather than a segregation of phonetic feature selectivity within each region, we found phonetically-selective electrodes within both Zone 1 and Zone 2, where the distribution of phonetic feature representations was similar across the two areas. When we analyzed responses to manipulated speech sounds, such as time-reversed speech and spectrally rotated speech, onset responses were conserved. These findings demonstrate a fundamental organizational property of the human auditory cortex that has been previously unrecognized.

TT-F-20 Intrinsic functional architecture of Wernicke's, Broca's, and Geschwind's areas of the human speech comprehension network

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Several models have been proposed to describe functional cortical pathways linking superior temporal cortex (STC) and heteromodal target regions in frontal and parietal cortex that facilitate speech comprehension. However, the functional architecture elaborated by these models diverge both at the level of the STC and their heteromodal targets. The goal of the current study is to address critical gaps in our knowledge and test competing models of cortical speech comprehension by examining intrinsic functional circuitry of the STC and network structure within this distributed system. We analyzed resting-state fMRI data collected in 131 neurotypical adults from the Human Connectome Project as well as a replication dataset collected at Stanford. To examine intrinsic functional circuitry of the speech comprehension network, we first took a data-driven approach using a novel algorithm to parcellate the STC based on both local and global temporal features in the fMRI time-series. We then investigated connectivity of these STC subdivisions, as well as the connectivity of STC along its anterior-posterior axis, to multiple prefrontal and parietal targets. Finally, we used graph theoretic measures to examine network properties of the speech comprehension network. Results can be summarized as follows: (1) The Superior Temporal Sulcus (STS) forms a distinct functional cluster within the STC based on local and global connectivity features, and relative to the Superior Temporal Plane (STP), has greater connectivity to IFG and IPL; (2) STS has greater connectivity with BA 47 and PGp compared to other IFG and IPL nodes; (3) Graph theoretic measures show that this distributed brain system segregates into three distinct communities, including STP, STS and frontoparietal communities. In conclusion, convergent results from consensus clustering, seed-based connectivity, and graph theoretic analysis revealed the large-scale structure of the cortical speech comprehension network.

TT-G-21Functional organization of human auditory cortex: An intracranial electrophysiology perspective

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The current model of monkey auditory cortex organization defines core, belt, and parabelt fields. The location and functional specialization of these fields in humans is unclear. Intracranial recordings in neurosurgical patients using a wide array of sound stimuli and tasks offer an opportunity to clarify the extent of homology between this model and human auditory cortex. Responses within posteromedial Heschl's gyrus (PMHG) represent acoustic attributes of sounds with short latencies and high temporal precision, and thus are characteristic of core auditory cortex. Spectral degradation of speech does not strongly modulate these population responses, and the activity is comparable when listening or speaking. Early activity is resistant to general anesthesia, and responses are not strongly modulated by task. Responses within anterolateral Heschl's gyrus (ALHG) and lateral superior temporal gyrus (STG) do not support their interpretation as belt and parabelt, respectively. STG can be more strongly activated by simple non-speech or spectrally degraded speech sounds than ALHG, and display greater temporal precision and shorter onset latencies. Within both ALHG and STG, responses are modulated by task, suppressed during self-vocalization, and abolished under general anesthesia. Activity within auditory-related areas, including middle temporal, supramarginal gyrus and prefrontal cortex, is modulated by sound-related tasks and correlates with performance. Direct recordings from human auditory cortex reveal a more complex hierarchical organization than that envisioned by the current monkey model. Population response properties do not support interpretation of PMHG, ALHG and STG as core, belt and parabelt areas, respectively. Instead, a portion of STG is hypothesized to represent a relatively early non-core processing stage (lateral belt). Further, auditory-related areas need to be considered when examining functional organization of sound processing in the human cortex.

Poster Sessions | Titles, Authors, Affiliations and Abstracts

The 6th International Conference on Auditory Cortex is pleased to present a wide range of current research through the poster sessions. Poster presentations have been divided into 3 sessions and arranged based on poster themes. All posters will be available to view for the duration of the conference.

Poster Session 1 | Monday, September 11, 3:30 PM – 6:00 PM

Poster Session 2 | Tuesday, September 12, 3:30 PM – 6:00 PM

Poster Session 3 | Thursday, September 14, 3:30 PM – 6:00 PM

The poster numbers are divided first by session, then by theme and finally with a unique number:

Session – Theme – Board Number (eg. 1-A-1)

Themes

A - Novel Neurotechnologies
B - Thalamocortical Circuitry and Function
C - Multisensory Processes
D - Correlates of Auditory Behavior/Perception
E - Neuroethology and Communication
F - Brain Processing of Language
G - Hierarchical Sensory Organization
H - Subcortical Auditory Processing
I - Auditory Disorders
J - Auditory Memory and Cognition
K - Cross-Species Comparisons
L - Neural Coding

Poster Session 1 | Monday, September 11, 3:30 PM – 6:00 PM

1-A -1 VSAD: A new battery for the evaluation of visuo-spatial abilities in deafness

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People that are deaf or are hard of hearing particularly rely on visuospatial perceptual and action abilities, not least for communication using sign language. Unfortunately, hearing loss can lead to vestibular function deficits that may impact cognitive and visuospatial behaviors. In this poster, we will present a new battery of tests for the evaluation of visuo-spatial abilities in deafness (the VSAD). The VSAD will use computerized tests presented on a WACOM tablet, developed with DiagnoseIS software (Metrisquare Company). The main functions that we propose to evaluate with this battery include visual perception, selective visual attention, visuospatial working memory, mental rotation and reproductive

abilities (two dimensions). Each test, as well as the computerized system will be explained. We propose that the use of new computerized technology for the tests will allow greater precision and reduced variance in the different measures, as well as additional dependent variables such as reaction time and response efficiency, not possible in traditional paper and pencil tests. In addition, the simplification of the tasks (recording and automatic correction of the data), will improve contact between the patient and the practitioner, and provide more time to the practitioner for listening to the patient, and qualitatively understanding the patients various difficulties. The test will also provide economic savings (with time in report writing, and increasing the ability of the clinician to handle more evaluations).

1-A -2 Mesoscopic topographically measurements of the auditory cortex with newly developed flexible and transparent multichannel electrodes

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Neurons in the brain are topographically organized into functionally distinct regions. For example, different sound frequencies in auditory cortex are represented by spatially distinct populations of neurons. Many current studies concentrate on recording of these neurons at the single cell level. However, the large number of cells makes it difficult to assess emergent properties which arise from the combined activity of the whole population. One approach of addressing this challenge are mesoscopic activity recordings at the level of the micro-electrocorticogram. Here we developed a novel, thin-film electrode array which can achieve micro-electrocorticographic recordings with high long term stability and signal-to-noise-ratio. The highly flexible, transparent, micro scale electrode array contains 32 recording sites on a transparent polyimide substrate. Long-term signal quality was evaluated on epidural auditory evoked potentials and tonotopic maps of in A1 of the awake Mongolian gerbil. The correct placement of the arrays in A1 was confirmed by online tonotopic mapping during surgery. Different surgical approaches were evaluated for their influence on signal stability and signal quality. Recordings were characterized by high peak-to-peak amplitudes of evoked potentials, which decreased relatively slowly over time. Even after several weeks post implantation the number of working channels and electrode impedance were stable and auditory evoked potentials could be recorded at the single trial level. Compared to previous results, we find higher inter-channel separability confirming a low cross talk between electrode sites. Due to a novel impedance reduction technique, thermal noise of the electrode contacts is below one microvolt. Due to the transparence of the substrate material, recordings can be combined with optogenetic stimulation and optical recording techniques, such as voltage sensitive dye recordings.

1-A -3 Hearing loss and neurotechnology: New approaches to improve speech perception

Lee Miller[1], Andrew Kessler[1], Britt Yazel[1], Kristina Backer[1], Markham Anderson[1], Nathaniel Guttierrez[1], Laurel Lawyer[1], Sanjay Joshi[1], David Corina[1]
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Understanding speech in noisy 'cocktail party' environments is the most profound daily challenge for listeners with hearing loss. Unfortunately, present approaches are limited both in i) diagnosing how different listeners fail to understand speech-in-noise and ii) designing aids and other assistive devices to cope with dynamic, acoustically cluttered scenes. Recent work in our lab uses auditory neuroscience with neuroengineering to advance both these aims. First, we have developed a novel EEG method that provides a rapid, hierarchical view into the functional health of the auditory-speech system - from brainstem to cortex - including how different processing stages may interact. Combining natural speech acoustics with FM sweep chirps, this CHEECH (chirp-speech) approach is adaptable to virtually any speech corpus and real-world perceptual, linguistic, or cognitive task. We will describe how it allows us to characterize auditory/speech development and auditory-visual crossmodal plasticity in children with cochlear implants, and how it may reveal fine temporal processing deficits in older adults with 'hidden hearing loss'. Furthermore, the CHEECH approach is well suited to study ecologically valid mechanisms in non-human primates and other model species. A second project in our lab develops an assistive device that uses eye gaze tracking and microphone array beamforming to serve as an "attentional prosthetic": wherever a listener looks, she will hear that sound best. The system is implemented on a mobile platform (Android) and incorporates virtual 3-D acoustic cues (HRTFs or head related transfer functions) to improve real-world comprehension both in individuals with hearing loss as well as healthy listeners in 'cocktail parties'. Funding sources for this research include NIH-NIDCD (R01DC014767), the NIH-funded UC Davis Clinical and Translational Science Center (NIH-1UL1TR001860-01), Starkey Hearing Technologies, Google, and Oculus/Facebook.

1-B -8 Abnormal cortical spike timing in Cdhr15+/- mutant mice displaying a reduced number of auditory cortex parvalbumin interneurons

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The interplay between excitation and inhibition is thought to control the timing precision of spike patterns elicited by communication sounds such as speech. In particular, inhibitory interneurons respond with short latency, great temporal precision and transient spiking to such sounds. However, the functional role of inhibition at the cortical level in processing complex sounds is not completely clarified yet. Here, we studied Cdhr15+/- heterozygous mutant mice, which have a reduced number of inhibitory parvalbumin expressing (PV+) interneurons restricted to the auditory cortex only, in association with a suseptibility to audiogenic seizures during the critical period. We aimed at characterizing the spiking and local field activity in the primary auditory cortex, the thalamus and the inferior colliculus of these mutants, in response to various transient or continuous, narrowband or broadband sounds, by using multi-electrode in vivo recordings. In Cdhr15+/- mice, while the auditory thresholds at the brainstem and cortical levels were normal, we found many dramatic changes in the activity of the primary auditory cortex, including the abnormal presence of spontaneous as well as evoked bursts of spiking activity, a decreased onset and increased duration of neural responses to sounds, and local field potentials of larger amplitude and longer duration when compared to wild-type littermates. Such defecits were not present in the auditory thalamus and the inferior colliculus of Cdhr15+/- mice that were recorded simultaneously to the auditory cortex. Although the susceptibility to audiogenic seizures typically ceased beyond the critical period in Cdhr15+/- mice, the abnormal cortical bursts were still present, suggesting that the possible compensation mechanisms mitigating the vulnerability to seizure after the critical period cannot restore the precise timing of the auditory cortex neural response.

1-B -9 Experience is required for development of longer-range, but less for local cortical connectivity

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The connectivity of cortical neuronal networks decisively affects their processing potential, and eventually the perception. The contribution of intrinsic (mainly genetical) and extrinsic (mainly experience-dependent) factors to the development of cortical connectivity is not well understood. An animal model of the complete congenital deprivation in which the activation of deprived modality can be successfully reversed in adulthood can be employed to study differential effects of these two factors on the adult cortical connectivity pattern. For this purpose, multiunit activities from 6 congenitally deaf cats (CDC) and 5 hearing controls were recorded simultaneously in primary (A1) and secondary posterior auditory field (PAF) by means of microelectrode arrays. The auditory nerve was electrically stimulated via cochlear implant. The cortical responses were evoked by electrical pulse trains (3 pulses at rate of 500Hz). The effective connectivity between the simultaneously recorded cortical positions was computed using transfer entropy approach. In CDCs, the effective connectivity analysis has revealed preserved local cortical connectivity (up to the ~400 µm). The connectivity strength, however, decreased rapidly with increasing distance between the neuronal populations in the deprived animals resulting in weakly connected clusters within the auditory cortex. In contrast, the normally hearing (experienced) animals expressed balanced local and longer distance connectivity pattern which was shown to be important for maximal computational power and flexibility of neuronal networks. In conclusion, we have found that local connectivity is preserved in the CDCs and hence is not essentially dependent on experience. The long-range connectivity was, however, different in deaf cats and thus it appears to be cardinally controlled by extrinsic factors. The experience is thus inevitable for proper cortical function by integrating local cortical subnetworks into one functional unit.

1-B -10 Spectrally-directed attention in human auditory cortex is topographically organized and related to myeloarchitecture

Frederic Dick[1], Matthew Lehet[2], Martina Callaghan[3], Tim Keller[2], Martin Sereno[4], Lori Holt[2]
[1]Birkbeck College, University of London, [2]Carnegie Mellon University, [3]University College London, [4]San Diego State University

Auditory selective attention is vital in natural soundscapes. But, it is unclear how attentional focus on the primary dimension of auditory representation - acoustic frequency - might modulate basic auditory functional topography during active listening. Using a novel functional paradigm combined with quantitative MRI, we establish that human frequency-band-selective attention drives activation both in myeloarchitectonically-estimated auditory core, and across the majority of auditory cortex. The attentionally-driven frequency selectivity and response profile show strong concordance with sensory-driven tonotopic maps and response profiles in the same subjects. The frequency bands that evoke the least response from input and from attention also correspond closely. Finally, patterns of local spatial correlation between the strength of frequency selectivity and degree of cortical myelination suggest shared functional and anatomical 'fault lines' that may underlie intrinsic auditory regionalization.

1-C-19 Auditory N1 morphology associated with dynamic visual gestures

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Previous research has shown that auditory speech syllables in noise were processed more quickly (decreased N1 latency) when accompanied with a visual stimulus of a moving face - either the speech gesture or an unrelated chewing motion; however, when the visual stimulus was the matching speech gesture the amplitude of the N1 response also decreased (Gilbert, Lansing, & Garnsey, 2012). The current study will investigate if timing alterations of the auditory cortical event-related potential N1 are specific to hearing speech while seeing facial motion, or if a latency decrease also occurs when hearing speech and seeing hand motion. In addition, auditory processing of speech syllables will be compared when paired with either a linguistically meaningful dynamic gesture (articulatory gesture on the face, finger spelling) or a gesture with no specific linguistic meaning (chewing motion, random hand motion). Preliminary results will be presented.

1-C-20 Early sensory deprivation alters the morphology of supragranular pyramidal neurons in primary sensory cortices

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Multisensory integration in low-level sensory areas like the primary auditory (A1), somatosensory (S1), and visual cortex (V1) is substantially mediated by direct interconnections between them. Recently, we have shown that early deprivation of the senses (hearing, touch, vision) leads to an increase of these multisensory intracortical connections via axonal reorganization processes, which is accompanied by an increase of the functional connectivity but a decrease of the stimulus-induced activity in the deprived and spared areas at the end of the critical period. Here, we investigated how the loss of early sensory experience influences the dendritic morphology of supragranular pyramidal neurons in A1, S1, and V1. Young Mongolian gerbils were sensorially deprived by either bilateral transection of the sciatic nerve at postnatal day (P) 5, bilateral ototoxic inner hair cell damage at P10 (i.e., before ear canal opening), or by bilateral enucleation at P10 (i.e., before eye opening). At P28, which demarcates in development the end of the critical period, brain sections of the deprived and control animals were stained using the Golgi-Cox method. Afterwards, the morphology of supragranular pyramidal neurons was studied by means of the NeuroLucida system (MicroBrightField). Scholl and branch analyses showed that early sensory deprivation leads to a general increase of dendritic branching, i.e., to longer and more widely branched basal and apical dendrites in the deprived and spared cortical areas. On the other hand, the overall number of dendritic spines and consequently the spine density decreased. In conclusion, previous and recent results suggest that the loss of early sensory experience induces an increase of multisensory axonal projections but a pruning of their postsynaptic targets (dendritic spines), which may lead to a reduced stimulus-induced activity in the deprived and spared cortical areas but a stronger functional connectivity between them.

1-C-21 Multisensory effects in natural audiovisual speech processing are reflected in EEG predictions

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Our ability to integrate auditory (A) and visual (V) information can greatly benefit speech comprehension, especially in challenging listening environments. However, the neural mechanisms underlying this integration, and specifically how visual speech influences auditory speech perception - are still not well understood, especially in the context of natural, continuous speech. Recent work has sought to address this issue by "decoding" stimulus features from EEG signals of subjects presented with unisensory (A and V) and multisensory (AV) speech. This approach has revealed multisensory effects in the fidelity with which EEG tracks the dynamics of congruent audiovisual speech in quiet (Crosse et al., 2015), and found these effects to be enhanced in the presence of background noise (Crosse et al., 2016).

However, this approach is constrained by its reliance on a mapping between the EEG signal and the speech envelope - a very impoverished measure of the speech signal. As such, it can be difficult to mechanistically interpret neural signatures based on this measure. This could be remedied by the use of an approach based on forward-encoding models. This approach allows mapping of more specific representations of speech such as its spectrogram or phonemes to the EEG dynamics, enabling a more fine-grained interpretation of the hierarchical processing of AV speech. However it is unclear whether or not forward encoding analysis has the sensitivity to pick up on multisensory effects in the context of natural speech. Here, using the speech envelope as a first attempt, we demonstrate that forward modeling of EEG can index nonlinear multisensory interactions in the context of natural AV speech. Following on from this, a broader variety of forward encoding models, such as those based on phonemes and phonetic features, are employed to thoroughly probe the neural generators, time-course and hierarchical stages of these multisensory interactions under varying acoustic environments.

1-D -26 Prestimulus influences on auditory perception - Consistency along the life-span

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The quality of an auditory percept depends not only on the acoustic input but also on the brain state before stimulus presentation. While many studies have shown that perception can vary as a function of the phase or power of rhythmic brain activity prior to the stimulus, it had remained unclear whether these effects relate to earlier sensory- or late and decision-related processes. We have addressed this question in young (<30 yrs) and elderly (>60 yrs) volunteers by combining psychophysical tasks (frequency and intensity discrimination) with a single trial EEG analysis that was designed to specifically probe pre-stimulus influences within distinct but task-related EEG components. Using regression modelling we linked pre-stimulus phase/power in distinct bands with the task-relevant sensory evidence reflected by linear discriminant components obtained from the EEG activity at different post-stimulus latencies, and with the subjects choice. Within auditory networks we found that phase had no direct influence on choice, whereas power in task-specific frequency bands affected the encoding of sensory evidence. Within later-activated fronto-parietal regions, theta and alpha phase had a direct influence on choice, without involving sensory evidence. These results delineate two consistent mechanisms by which pre-stimulus activity shapes perception. Importantly, we found that these mechanisms are in principle conserved across the tested age groups, but systematically engage lower frequencies in the elderly.

1-D -27 Mapping frequency specific tone predictions in human auditory cortex at high spatial resolution

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Auditory inputs reaching our ears are often incomplete, but our brains nevertheless transform them into rich and complete perceptual phenomena, such as meaningful conversations or pleasurable music. It has been hypothesised that our brains extract regularities in inputs, which enables us to predict the upcoming stimuli, leading to efficient sensory processing. To complete gaps in perception and achieve a complete reconstruction of stimuli, tone predictions need to be encoded with similar specificity as perceived signals. Here we used high-field functional magnetic resonance imaging to ask whether early auditory regions encode the frequency of predicted tones, one of the most defining features of auditory perception and anatomical organisation. Two pairs of tone sequences were presented in ascending or descending directions, with the last tone omitted in half of the trials. Every pair of incomplete sequences contained identical sounds, but was associated with different expectations about the last tone (i.e. a high or low frequency target), which allowed us to disambiguate predictive signalling from sensory-driven processing. Obtained responses were used to construct preference maps of complete sequences, incomplete sequences and pure target presentation. Comparison of response profiles revealed that the target frequency was encoded with similar specificity and preference during their presentations, as well as during omissions. This speaks to frequency-specific encoding of predicted tones in all subregions of the auditory cortex. Importantly, frequency-specificity of predictive signalling was observed already at the earliest levels of auditory cortical hierarchy ? in the primary auditory cortex. Our findings provide evidence for content-specific predictive processing in the auditory cortex, starting at the earliest cortical levels.

1-D -28 Probing neural mechanisms of auditory streaming in humans by transcranial direct current stimulation

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One hypothesis concerning the neural underpinnings of auditory streaming states that frequency tuning of tonotopically organized neurons in primary auditory fields in combination with physiological forward suppression leads to separable representations of high-frequency A and low-frequency B tones. The extent of spatial overlap between the tonotopic activations of A and B tones is thought to underlie the perceptual organization of streaming sequences into one coherent or two separate streams. The present study attempted to interfere with these mechanisms by transcranial direct current stimulation (tDCS) and to probe behavioral outcomes reflecting the perception of ABAB streaming sequences. We hypothesized that tDCS by modulating cortical excitability causes a change in the separateness of the representations of A and B tones which leads to a change in the proportions of one-stream and two-stream percepts. To test this, twenty-two subjects were presented with ambiguous ABAB sequences of three different frequency separations (ΔF) and had to decide on their current percept after receiving sham, anodal, or cathodal tDCS over the left auditory cortex. We could confirm our hypothesis at the most ambiguous ΔF condition of 6 semitones. For anodal compared to sham and cathodal stimulation, we found a significant decrease in the proportion of two-stream perception and an increase in the proportion of one-stream perception. To further support our hypothesis, we replicated these results in simulations of auditory cortex using a computational model that is based on the anatomy and physiology of the AC. The results demonstrate the feasibility of using tDCS to probe mechanisms underlying auditory streaming through the use of various behavioral measures. Moreover, this approach allows one to probe the functions of auditory regions and their interactions with other processing stages. Funding This work was supported by the 'DFG' [SFB/TRR31].

1-D -29 Representation of pitch across spectral regions in human auditory cortex

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Pitch perception relies on the ability of the auditory system to extract the fundamental frequency (f0) from the spectral components of a periodic sound. Neurons in the low-frequency anterolateral border of primary auditory cortex (AC) in marmoset monkeys have been shown to respond selectively to the f0 of harmonic complex sounds independently of their frequency content. In human cortex, on the other hand, direct evidence for fo pitch tuning is lacking. Evidence for pitch selectivity in human cortex stem solely from imaging studies comparing responses to sounds with varying degrees of saliency of the pitch percept, e.g. with different spectral resolvability. Here, we used functional MRI and population receptive field mapping techniques to examine pitch tuning in human auditory cortex. During fMRI, 30 participants were presented with harmonic complex tones gradually changing in pitch f0 between 100 and 800 Hz and filtered either in a low or a high frequency region resulting in different degrees of harmonic resolvability. For each AC voxel, we estimated the f0 tuning for the low-frequency filtered tones and used this to predict the response to the high-frequency filtered tones, and vice versa. A tonotopically low-frequency region at the anterolateral border of Heschl's gyrus accurately predicted the f0 variation across the two spectral regions. In addition, a more global low-to-high pitch gradient emerged across the AC in anterior-to-posterior direction. Results also indicated that differences in the extent of pitch selective cortex between the individual participants predicted their behavioural pitch discrimination thresholds. Together, our results indicate a topographical representation of pitch independently of spectral content and resolvability in human auditory cortex.

1-D -30 How are familiar voices represented in auditory cortex?

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The ability to understand speech in the presence of competing talkers is fundamental to successful verbal communication. When two talkers speak simultaneously, intelligibility improves by 10-20% when target speech is spoken by a familiar talker, such as a friend or spouse, than by someone unfamiliar (e.g. Johnsrude et al., 2013). Nevertheless, how cortical representations of familiar voices facilitate improved intelligibility is currently unknown. We recruited friends and couples who had known each other for > 6 months and who spoke regularly. We used functional magnetic resonance imaging (fMRI) to measure brain activity evoked by familiar and unfamiliar voices. Participants were presented with sentences from the BUG (Boston University Gerald; Kidd et al., 2008) corpus, which follow the structure <Name><verb><number><adjective><noun>. Participants heard sentences spoken by their familiar partner and by two unfamiliar talkers, who were the partners of other participants. On two-talker trials, participants heard two BUG sentences spoken simultaneously by different talkers. They were cued visually to attend to the sentence with a particular target name ("Bob" or "Pat"). In the Familiar Target condition, the target sentence was spoken by the familiar talker and the masker sentence was spoken by an unfamiliar talker. In the Both Unfamiliar condition, the target and masker sentences were spoken by the two unfamiliar talkers. On single-talker trials, participants heard one sentence spoken by either their familiar or one of the two unfamiliar talkers. We will investigate which auditory cortical regions are sensitive to voice familiarity and to the magnitude of the familiar-voice intelligibility benefit (measured outside the scanner). We predict that patterns of activity evoked by familiar voices may be more robust to a competing talker than those evoked by unfamiliar voices. The results will improve knowledge of how familiar voices facilitate intelligibility.

1-D -31 Preference test of sound among multiple alternatives in rats

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To measure intrinsic and induced preference of arbitrary stimuli are of great value when studying sensory perception in animal models. We developed a novel setup of behavioral experiment for rats to quantify preference of test sound among multiple alternatives. In the setup arena, several tones were presented according to the location of free-moving rats. Assignment of location to each tone changed in every trial. Rats were supposed to stay longer in preferred sound, seek preferred sound and move away from the dislikable sound in the arena. In the test groups of rats, the preference of test tone was manipulated by appetitive classical conditioning, where 20-kHz tone was associated with microstimulation of dopamine system in the ventral tegmental area. Two different indices were used to quantify the preference: (i) staying time during presentation of each test tone; (ii) transition matrix of initial and end tone in every trial. In naïve rats, we found significant differences in both indices, suggesting that rats intrinsically prefer 40 kHz to 10 kHz tone. Appetitive conditioning of 20 kHz and VTA microstimulation did not change time spent in 20-kHz tone location with respect to that of naïve rats; yet, the transition-matrix based index revealed behavioral changes due to the conditioning such that rats were more likely to move toward 20 kHz location than to move away from 20 kHz location. Such behavioral change was not observed after merely exposing to 20 kHz tone. Thus, with an adequate index, our behavioral test is able to unravel intrinsic and induced preferences of animals among multiple alternatives.

1-D -32 Developmental hearing loss impairs fast temporal processing

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Fluctuations in sound level support speech comprehension, and perceptions of rhythm, prosody, and pitch, depending on the rate of amplitude modulation (AM). However, AM sensitivity may be vulnerable to hearing loss (HL) during its prolonged period of maturation. In fact, the processing of rapid (>100 Hz) modulation rates may be particularly impaired (e.g., Park et al., 2015). Here, we sought to determine whether behavioral and neural AM detection thresholds display a similar sensitivity to developmental HL. Normal hearing (NH) adult gerbils, and those reared with conductive HL, were trained and tested on an appetitive Go-Nogo AM detection task (Go stimuli were broadband noise modulated at 64-512 Hz across a range of depths; Nogo stimulus was unmodulated noise). HL animals displayed poorer behavioral thresholds than NH animals at all AM rates, but performance was much worse at very fast rates, 256 and 512 Hz. To determine whether these perceptual deficits were attributable to degraded encoding mechanisms within the auditory brainstem, we recorded envelope following responses (EFRs) across a range of AM rates and depths from NH and HL animals that had been trained previously on the AM detection task. NH animals displayed similar EFR and behavioral thresholds, whereas HL animals displayed EFR thresholds that were better than those obtained behaviorally. This suggests that a neural deficit associated with behavioral impairment may be found downstream of the auditory brainstem. To test this idea, we are recording extracellular responses from ACx neurons while gerbils perform the AM detection task.

1-D -33 Self-induction of sound motion does not attenuate the auditory motion-onset response

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When we move through our environment we cannot help but make some noise. Electroencephalography studies have shown that the event-related potentials in response to self-initiated sounds are attenuated, in particular the so-called N1 component at about 100 ms after stimulus onset. This attenuation has been proposed to be the effect of an internal forward model based on a concurrent efference copy of the motor command. In the current study we asked whether the attenuation due to self-initiation of a sound would also affect a later event-related potential - the so-called motion-onset response - that arises in response to moving sounds at about 150-300 ms after motion onset. To this end, volunteers were instructed to "push" static sounds either to the left or to the right by moving their index fingers. Sound motion was induced with in-ear head-phones by shifting interaural time and intensity differences and thus shifting the intracranial sound image. We compared the motion-onset responses under two conditions: a) congruent, and b) incongruent. In the congruent condition, the sound image moved in the direction of the finger movement, while in the incongruent condition sound motion was in the opposite direction of the finger movement. In a sample of 19 volunteers, clear motion-onset responses with a negative cN1 component peaking at about 160 ms and a positive cP2 component peaking at about 230 ms after motion-onset were obtained for both the congruent and in-congruent conditions. However, the motion-onset responses did not significantly differ between congruent and incongruent conditions in amplitude or latency. Thus, our study did not provide evidence that the motion-onset response measured by EEG is attenuated when sound movement is more predictable following the direction of self-movement. In future studies, we plan to test for an attenuation of the motion-onset response with more naturalistically spatialized sounds, using a loudspeaker rather than a headphone setup.

1-D -34 Human auditory cortex representation of spatial separation between concurrent sounds

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We applied magnetic resonance imaging at 7 tesla to measure human brain activity in response to spatially-separated concurrent sounds. Stimuli were spatialized amplitude-modulated broadband noises, recorded for each participant via in-ear microphones prior to scanning. Using a linear support vector machine classifier, we investigated if sound location and/or spatial separation between sounds could be decoded based on activity in Heschl's gyrus and the planum temporale. We trained the decoder with trials that varied in either: (1) target location (90º or 45º, midline at 0º) with constant spatial separation from concurrent sound (either 0º, 90º, or 135º separation towards contralateral hemifield), or (2) spatial separation between target and concurrent sounds (90º or 135º separation). For each participant, we determined the decoder's chance performance level via permutations, and tested the group's difference from chance ($N = 10$, Wilcoxon signed-rank test, corrected with false discovery rate $q < 0.05$). The decoder distinguished patterns of activity associated with different spatial separations, but only if the difference in spatial separation arose by a change from the midline to 45°, and not 45º to 90º. This sensitivity to the midline is consistent with human auditory spatial acuity. The decoder could not distinguish different sound locations when the spatial separation between sounds was constant. This was true even when the concurrent sound moved from the midline to 45º. We propose that the decoder's unique success for distinguishing changes at the midline (vs. in the periphery) and changes in spatial separation (vs. constant spatial separation) indicates that auditory cortical spatial processing reflects the acuity of human spatial perception, and that it is optimized for stream segregation via spatial cues.

1-D -35 Spiking activity in auditory cortex to identity-preserving changes in sounds

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The auditory system transforms acoustic stimuli into representations that subserve perception, recognition, and behavior. One major challenge faced by the auditory system is the creation of sound representations that are invariant to identity-preserving transformations. Indeed, sound recognition by human listeners is invariant to changes in the stimulus due to variation in the pitch of speakers' voices, the location of the sound source, the amount of background noise, etc. The brain areas, neural mechanisms and computations that provide the basis for a listener's tolerance to identity preserving changes are unknown. To address the neural basis of invariant recognition, we conducted large-scale recordings from the auditory cortex of rhesus monkeys while they listened to natural sound exemplars (animal vocalizations and natural background noises) and identity-preserving transformations of these exemplars. These transformations included sound-source location and room reverberation. Additionally, as controls, we presented scrambled versions of these sounds. These scrambled versions were statistically matched to these natural exemplars but could not be identified as originating from the same source as the original sounds. We recorded with MicroProbes' 96-electrode Microwire Brush Array simultaneously from 3 areas of auditory cortex: anterolateral belt (AL), middle-lateral belt (ML), and primary auditory cortex (A1). We report how identity-preserving transformations of sounds are represented in the spiking activity of neurons in these three brain regions. In particular, we describe the degree to which neural populations codes support perceptual representations of invariance.

1-D -36 A task-dependent gradient of spatial sensitivity in human auditory cortex

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The aim of the present study was to investigate the dynamic character of spatial sensitivity in distinct cortical auditory areas in humans. Specifically, we tested whether and how cortical spatial tuning is modulated by engaging in a sound localization task, a sound identification task, or listening to sounds passively. We used functional magnetic resonance imaging (fMRI) to measure the blood-oxygenation level dependent (BOLD) response to amplitude-modulated (AM) white noise at seven different locations (-90^{o} to $+90^{o}$ in equidistant steps of 30^{o}). Sounds were spatialized with subject-specific binaural recordings and presented in three different task conditions: passive listening, sound identification, and sound localization. In the sound identification task, participants were instructed to detect a deviant sound (a click train). In the sound localization task, participants were instructed to detect a change in sound location within a trial. For each voxel we computed a response azimuth function (RAF) and, based on the RAF, spatial sensitivity. We additionally performed tonotopic mapping measurements in the same participants and employed the resulting frequency preference and selectivity maps to parcellate the auditory cortex into a core region, belt region, and planum temporale. We observed an anterior-to-posterior gradient of spatial sensitivity in the passive listening and sound identification condition: spatially sensitive voxels were less prevalent in the core than in PT, and spatial tuning was broadest in the core and sharpest in PT. Engaging in a sound localization task resulted in sharper spatial tuning in the left core region, abolishing the inter-area differences in spatial sensitivity. Response sharpening was a result of reduced BOLD responses to least-preferred locations. The present findings confirm the role of PT in human sound location encoding, and highlight the dynamic potential of spatial tuning in the auditory core depending on task requirements.

1-D -37 Distinct temporal processing schemes for speech and music

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Speech and music share similar temporal attributes such as rhythm and phrasing, but we perceive these attributes differently. Yet it is still unclear how temporal processing in the brain contributes to the differences our perception of speech and music. One key issue is that typical research techniques using simplistic and repetitive stimuli may show results that are hard to extend into a naturalistic context. Here, we used electroencephalography (EEG) to examine temporal properties of neural activity that reflect the neural processing of long, continuous streams of real speech and music. We focused on the time-varying EEG signals with the largest variability, and we used a modeling approach to identify temporal properties of the EEG that could best reconstruct the envelopes of the stimuli. By decomposing the EEG signals into their fine-structure, envelope, and time-varying mean we were able to separately examine neural activity associated with time-varying phase and power fluctuations, both of which have been found to reflect speech and music processing in previous studies. We show that the slow, second-long fluctuations from the time-varying mean of the EEG signal are dominant in reconstructing the envelope of speech. In contrast, the faster fluctuations in the time-varying fine structure and envelope of the EEG signals are more useful for reconstructing the envelope of music. And unlike the reconstruction for speech, including the time-varying fine structure and envelope of the EEG improves the reconstruction accuracy of music over using the raw EEG alone. Our results identify distinct temporal processing schemes for speech and music that reflect the different ways in which the brain parses these two stimuli.

1-D -38 Prolonged development of temporal integration in auditory cortex

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Auditory perception has a varied developmental timeline, as some percepts reach maturity early in life while others mature throughout adolescence. Behavioral studies show prolonged developmental trajectories for detecting silent gaps in noise and short duration stimuli, indicating immature temporal integration abilities. Immature performance continues well past when the peripheral auditory system has adult-like function, implying more central mechanisms. Consistent with this, cortical inhibition also has a prolonged developmental trajectory, with IPSC amplitudes and decay rates fully maturing very late in development. Despite these data, many neural studies of temporal processing in the central auditory system focus either on adult responses or on the robust changes that occur during early critical periods. Here we recorded responses to varying duration sound bursts at cell's best frequency from primary auditory cortex of awake, head-fixed Mongolian gerbils in adolescents (P25-30) and mature adults (P90-P130). Compared to adults, adolescent cells showed more sustained firing to short tones, along with decreased discriminability among durations. We hypothesized that a gap presented after a short lead burst would be less detectable for adolescent cells, as is seen behaviorally in humans, presumably due to the close apposition of the initial response and the response to the gap. To test this, we presented gaps of varying durations inserted at several delays relative to signal onset. Consistent with previous data, neural adult gap detection thresholds were higher as gaps were presented closer to signal onset. Adolescent gap detection thresholds showed the same pattern, but the increased thresholds for short delays between signal onset and gap were significantly higher than in adults. These differences may be due to immature cortical inhibition, and suggest a potential neural substrate for immature performance on temporal integration tasks in adolescents.

1-D -40 Do oscillatory dynamics of pre-stimulus EEG predict trial-by-trial fluctuations in auditory pattern identification?

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Recent electroencephalographic (EEG) research suggests that the state of ongoing oscillatory activity influences perceptual processes in humans. Specifically, pre-stimulus power and phase of oscillations predict performance in a number of visual and auditory tasks. The present work examines such effects in a rapid auditory processing task. On each trial, participants heard three 40-ms sinusoidal tones separated by 40-ms inter-stimulus intervals. One of the three tones was at a different frequency than the other two. Each participant's task was to indicate the order of the tones (low-low-high, low-high-low, etc.). An adaptive, one-up, one-down procedure was used to determine the frequency separation associated with each individual's 50% correct identification threshold. Afterwards, each participant completed 250 trials at this frequency separation threshold while EEG data were collected using a 68-channel array of electrodes. Resulting data were sorted into correct and incorrect trials to facilitate single-trial analysis of predictive pre-stimulus EEG features. Preliminary analyses, using a phase-opposition sum measure, suggest that pre-stimulus alpha band phase differs between correct and incorrect trials. Through multiple sessions of testing using the same participants we intend to examine the stability of these effects.

1-D -41 Multimodal assessment of training-induced plasticity of the cholinergic system

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During adulthood, brain plasticity is tightly regulated: it occurs only in the context of goal-directed behavior requiring sustained attention. The cholinergic system functions as a gating mechanism that enhances attention and thus regulates plasticity. Unfortunately, aging is associated with a progressive degeneration of the cholinergic system in rodents and humans alike. This in turn impairs the acquisition of skills acquired through learning or during functional recovery following neurological injury. Cognitive training has shown to enhance auditory processing in rats and improve working memory and attention in humans. However, its direct impact on the cholinergic system remains unknown. Our lab has undertaken a parallel animal and human study to assess the effect of cognitive training on the cholinergic system using positron emission tomography (PET). Here we present the first results of the animal cohort, using a combination of auditory training, PET, electrophysiology, and immunohistochemistry.

1-D -42 On the effect of interpersonal familiarity on auditory distance perception

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Auditory distance perception is a multidimensional phenomenon. Familiarity with the sound source is known to have an important effect on the distance perception as one of the cognitive cues. An auditory distance perception experiment to assess the effects of interpersonal familiarity on auditory distance perception is reported. The subjective experiment involves a binaural listening task. For all stimuli,

distances between 0.5 and 16 meters were simulated by convolving sound sources with a binaural head-related impulse response (HRIR). The participants were 12 heterosexual couples. It's been reported that each couple has known each other for at least 2 years with a daily interaction and, they were strangers to other participated couples. In order to investigate the effect of speaker familiarity, each subject listened and judged the distance of five different speech utterances from their partner (F0), the spectrally most similar stranger (F1) and the spectrally most dissimilar stranger (F2). Listeners' judgments of sound source distance suggest that interpersonal familiarity affects auditory distance perception positively for the Familiar (F0) and Unfamiliar (F2) conditions. These results also revealed another interesting point that other cognitive factors besides of the interpersonal familiarity (e.g. semantic feature of the utterances listened to) may be effective in auditory distance perception.

1-D -43 Rapid plasticity in auditory cortical receptive fields can be reproduced in a neural network model by changing synaptic strengths

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Objectives: The auditory cortex utilizes a variety of processing strategies to enhance the perception of important sounds in the presence of background noise. Rapid plasticity of receptive fields in the primary (A1) cortical neurons is observed during behavioral tasks that require discrimination of certain sounds. This rapid task-related change is believed to enhance the ability to selectively attend to one stream of sound in the presence of mixed sounds. However, the mechanism by which the brain evokes this rapid plasticity in the auditory cortex remains unclear. Methods: A neural network model was developed to investigate mechanisms by which cortical neurons can change their receptive fields. A sound signal was played into a model of the cochlea. The output of the cochlear model activated or inhibited integrate-and-fire neuron models to represent networks in the primary auditory cortex. Each neuron in the network was tuned to a different frequency. All neurons were interconnected with excitatory or inhibitory synapses of varying strengths. Action potentials in one of the model neurons was used to calculate the receptive field using reverse correlation, which could be directly compared to electrophysiological data. A genetic algorithm was used to optimize the synaptic strengths between neurons to produce receptive fields that matched experimentally recorded data. The neural network was then expanded to included inputs from higher brain regions to investigate neural mechanisms that could evoke rapid changes in receptive fields. Results and Conclusions: The genetic algorithm could determine the synaptic strengths to produce complex receptive fields observed experimentally. Altering the synaptic strengths could reproduce changes in the receptive fields observed in response to behavioral tasks. Extending the neural network to include top-down control from higher brain regions tested potential neural mechanisms that could produce rapid changes in the receptive fields.

1-E -81 Bilateral song processing in the zebra finch auditory forebrain reflects asymmetric sensitivity to temporal and spectral features

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Despite being commonly referenced throughout neuroscientific research on songbirds, reports of hemispheric specialization in the processing of song remain controversial. The notion of such asymmetries in songbirds is further complicated by growing evidence that even hemispheric specialization for speech in human auditory cortex is now considered to be a largely bilateral process. Today, a core group of studies agree that the auditory neural substrates in the left and right auditory cortices of humans process temporal and spectral elements within speech sounds, respectively. To determine whether songbirds process their conspecific songs in such a complementary, bilateral manner, we performed functional magnetic resonance imaging (fMRI) on 15 anesthetized male zebra finches while presenting them with (1) non-manipulated, (2) spectrally-filtered, and (3) temporally-filtered conspecific song. Our results revealed bilateral yet asymmetric sensitivity of both primary (Field L, analogue of primary auditory cortex or BA 41/42) and secondary (NCM, analogue of non-primary auditory cortex or BA 22) auditory regions to spectrotemporal features of song. On the one hand, temporally-filtered song elicited a bilateral decrease in neural responses compared to the other song types. On the other hand, spectrally-filtered song elicited significantly greater responses in left Field L and NCM than temporally-filtered or non-manipulated song while concurrently reducing the response relative to non-manipulated song amongst these same structures in the right hemisphere. This increased response in left and decreased response in right hemispheric structures to spectrally-filtered song suggests a respective selectivity for temporal and spectral information in left and right avian auditory forebrain structures. Further, these results suggest that humans and songbirds developed remarkably similar, yet different, strategies for processing complex, conspecific communication sounds.

1-F -83 Lexical and audiovisual influences on phoneme boundary recalibration: an fMRI study

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Listeners are capable of flexibly adjusting boundaries between phoneme categories using lexical and audiovisual information, as a means of adjusting to variability between speakers and accents. The present study compared these influences on phoneme boundary recalibration in order to determine similarities and differences at the neural level using high-field fMRI. Participants were exposed to blocked presentations of words and videos embedded with an individually determined, ambiguous token halfway between /oop/ and /oot/, selected from a 10-step continuum. Lexical blocks consisted of audio recordings of Dutch words ending in either phoneme, with the final syllable replaced by the token. During audiovisual exposure, video recordings of the speaker pronouncing pseudo-words visually appearing to end in the two phonemes were presented, with ending audio also replaced with the token. To measure recalibration, following each exposure block, a test phase was presented. Subjects heard the token and its two neighbors from the continuum, and were asked to report which phoneme they heard. The paradigm and stimuli were taken from a previous behavioral study that confirmed their efficacy. fMRI data was acquired with a 7T scanner while participants (N=6) completed the behavioral task, using a sequence with silent gaps during sound presentation. Preliminary results determined activation in superior and medial temporal gyri during both lexical and audiovisual exposure. Superior temporal gyrus activity was detected specifically during lexical exposure in contrast to visual cortex activity during audiovisual exposure. During lexical and audiovisual test phases, brain response patterns showed both convergence and divergence. Following both forms of recalibration, activity was present across auditory regions, although left prefrontal regions showed slightly increased sensitivity to audiovisual test phases compared to lexical tests, which may reflect differences in semantic processing.

1-F -84 Selective attention in a spectro-temporally complex auditory scene: a ferret cocktail party

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A key function of the auditory system is the segregation of competing sounds. An example of this is the Cocktail Party phenomenon, where a listener is able to attend to one talker in the presence of one or more competing talker(s). The mechanism serving this selective attention is not fully understood and at present no animal behavioural model employs human vocalizations to study it. Here we tested the feasibility of using an animal model in a selective attention task using human speech, while making neural recordings from auditory cortex. Five ferrets were trained to approach a central port, which initiated a stream of speech sounds lateralised from a speaker on either the left or right. They were required to wait at the centre until they heard a target word, at which point they responded at the side that the speech stream was presented from. After training, performance was significantly above chance for all those tested ($p<0.05$, bootstrap, chance = ~26%, average = ~63% correct). Animals (n=2, thus far) were then trained to selectively attend to one of two spatially separated competing streams and again respond to the target embedded within the attended stream. Performance was above chance in the presence of both babble speech (~47% correct) and another talker (~45% correct). Chronic recording electrodes were implanted bilaterally in auditory cortex and neural responses (spiking and LFP) were measured during behavioural testing. As would be expected the stream onset responses in the LFP were strongest hemisphere contralateral to sound presentation, and were larger in situations where there was no simultaneous distractor stream. Preliminary results demonstrate the potential of this behavioural model to allow closer inspection of the neural mechanisms that underpin the cocktail party phenomena.

1-F -85 Neural encoding of attended speech in primary and non-primary human auditory cortices

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Humans posses the ability to segregate one speaker from another, even when there is no spatial separation between them. Invasive human neurophysiology studies have shown a spectrotemporal representation of an attended speaker in superior temporal gyrus (STG) that rapidly changes depending on the attentional focus of the listener. However, how such a representation emerges in STG is unknown. In addition, the representation of speech in primary auditory cortex (Heschl's gyrus; HG) remains unexplored due to it's inaccessibility from the surface. Here, we used invasive depth electrodes and surface recordings to investigate the neural encoding of an attended speaker along the cortical auditory pathway. Subjects listened to a male and female speaker, both in isolation (single-speaker; S-S), and mixed together (multi-speaker; M-S), with no spatial separation between them. To characterize the tuning properties of each electrode site, we obtained their spectro-temporal receptive field (STRF). Electrodes in HG tended to respond at short latencies (~50 to 150ms) and were narrowly tuned, with some electrodes responsive to speaker-specific features (e.g., the fundamental frequency of the male speaker). These electrode sites retained this speaker-selectivity, even when that speaker was not being attended to. Electrodes in STG responded at longer latencies (~150 to 300ms), were more broadly tuned, showed relatively little speaker-selectivity, and responded preferentially for the attended speaker. Comparing the STRFs from the S-S condition with the M-S condition, the tuning properties of HG electrodes remained similar, whereas electrodes in STG changed their tuning properties to enhance / suppress the attended / unattended speaker. These results provide a descriptive account of how the features of an attended speaker are progressively processed along the auditory cortical pathway in a multi-speaker environment.

1-F -86 Unique roles for delta and theta frequency bands in the cortical analysis of temporal speech structure

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Speech perception entails the mapping of the acoustic waveform to its linguistic representation. For this mapping to succeed, the speech signal needs to be tracked across a large temporal range at high temporal precision in order to decode linguistic units (phonemes, syllables, words). Here we test how cortical processing of such temporal speech structure is modulated by higher-order linguistic analysis. To control the temporal scale of analysis, we used a novel sound-quilting algorithm that controls acoustic structure at different temporal scales (Overath et al., 2015). To control the linguistic content, we constructed speech quilts from both familiar and foreign languages. This ensures that any changes at the signal-acoustics level affect both languages identically, while manipulating the linguistic percept differently. Thus, neural responses that vary as a function of segment length, but are shared or similar across the two languages, suggest analysis at the signal-acoustics level, whereas neural responses that differ based on language familiarity imply the presence of linguistic processing. We recorded EEG while subjects listened to 6 s long English or Korean speech, quilted with 30 ms or 960 ms segment lengths. Neural entrainment to the speech quilt envelope, assessed via inter-trial correlation (ITC), in the theta band increased with segment length in both languages; however, ITC in the delta band increased with segment length only in English. This dissociation indicates that neural entrainment in the theta and delta frequency bands serves different functions: acoustic and linguist analysis of temporal speech structure, respectively. In particular, linguistic analysis tracks syllabic and word content that is preserved with increasing segment lengths. The results advance our understanding of the neural mechanisms underlying the acousto-linguistic mapping of temporal speech structure.

1-F -87 Representations of amplitude modulations in auditory onsets, ramp tones, and speech in the human superior temporal gyrus

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Making sense of complex auditory inputs requires temporally precise parsing of single events out of the auditory stream. Auditory event onsets are typically marked by an increase in amplitude, and previous animal and human studies identified the dynamics of amplitude rise at onset as a central feature encoded throughout the subcortical auditory pathway. Amplitude modulations, however, also mark changes within ongoing sounds, e.g. in the speech envelope. Yet, it is unknown how the human auditory cortex differentiates between amplitude rises in silence and within an ongoing sound, and whether onset encoding can account for tracking of the speech amplitude envelope. To address this, we designed tone stimuli containing amplitude ramps, rising from silence (RfS condition), or from an amplitude baseline (RfB condition). The sound intensity of ramps increased linearly to peak amplitude and returned to silence/baseline, with varying rates of amplitude change. We recorded local field potentials using intracranial multi-electrode arrays placed over the temporal lobes of five patients undergoing evaluation for epilepsy neurosurgery, as they passively listened to the tones. In both conditions, ramps elicited transient responses in the high gamma frequency range (HG, 70-150 Hz) in posterior (p) and middle (m) superior temporal gyrus (STG), with larger HG amplitudes for fast-rising ramps. We observed a striking double dissociation of response types: pSTG encoded the rate of amplitude change in the RfS condition only, whereas mSTG encoded the rate of amplitude change in the RfB condition only. Crucially, the rate of amplitude envelope modulation in continuous speech was also represented in mSTG, but not in pSTG. Our results reveal functionally and spatially distinct representations of sound onsets in silence and in background along STG. Moreover, our data suggest that speech amplitude tracking in mSTG may rely on the same neural mechanisms as the encoding of onsets in background.

1-F -88 Development of timing of turn-taking from adolescence to adulthood

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The recent study is part of a project which aims to study the neurocognitive development of language and auditory-motor coordination from adolescence to adulthood. In the first two studies of this project, we explored the development of communication skills, especially, the timing of turn-taking with behavioral methods. In everyday conversations, the gap between turns of conversational partners is most frequently between 0 and 200 milliseconds. The short transitions suggest that listeners are able to predict when a current turn is coming to an end and can time well their own turn to the end of a previous turn. Hence, timing of turn-taking in conversations relies on several processes: linguistic and timing predictions, and auditory-motor coordination. In this study, a button-press paradigm was applied to study turn-end predictions in the different age groups: in early adolescence (11-13 years), in late adolescence (15-17 years) and at adults (>21). We hypothesized that the performance for predicting turn-ends will improve with age. In a subsequent study, we explored in a group of adult participants how verbal working memory capacity and precise timing of the ending of non-verbal, auditory stimulation correlates with turn-end predictions.

1-G -102 Exploring the robustness of cortical sound encoding to real-world background noise

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In everyday listening, the sounds from sources we seek to understand are often embedded in background noise. This noise alters the pattern of spikes in the auditory nerve, often to a profound degree. In order to recognize sources of interest, the brain must to some extent become robust to the effects of these background noises. To study the neural basis of listening in real-world background noise, we measured fMRI responses in human auditory cortex to a broad set of thirty natural sounds, presented in quiet as well as embedded in thirty different everyday background noises (e.g., a bustling coffee shop, crickets chirping, heavy rain hitting pavement). We quantified the extent to which neural responses were robust to background noise by correlating each voxel's response to the natural sounds in isolation with its response to those same natural sounds mixed with background noise. We normalized this correlation coefficient by the reliability of the voxel's response measured across split halves of the data. This measure quantifies the extent to which a voxel's pattern of response across natural sounds is the same when the natural sound is presented in quiet and when it is embedded in noise. Responses in anatomically-defined primary areas (TE 1.1 and 1.0) were substantially affected by background noise (r2 ~ 0.40). However, voxel noise-robustness was substantially higher in non-primary areas, in some cases being hardly affected by the background noises (r2 ~ 0.85). Mean responses in primary and non-primary regions were both only slightly lower in the presence of background noise, indicating that the difference in robustness between regions was not due to the background noises differentially suppressing responses in primary areas. The results illustrate a method for studying the noise robustness of neural responses throughout human auditory cortex.

1-G -103 Frequency-selective sustained attention training modulates cortical and subcortical electrophysiological responses

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The process of singling out a sound stream, maintaining focus on this stream over time, and suppressing irrelevant or distracting sound streams is one that challenges many patient groups as well as younger children and healthy older adults. In the current study, we use a novel non-speech attentional paradigm to ask how cortical and subcortical auditory responses are modulated for attended and unattended sound streams, and how these responses may change with attentional training. Here, participants heard two tone streams with center frequencies an octave apart; the streams drew from a tone pool of three different frequencies per stream. The streams were made of a series of of 3-tone 'mini-sequences', with the high and low stream tones alternately presented; this allowed for analysis of subcortical frequency following responses as well as potential phase-locking of cortically driven EEG signals at the presentation rate of the attended stream. Subjects responded to repeated mini-sequences in the attended stream, while ignoring those in the unattended stream. Attending to the high but not the low frequency streams led to an increase in across-trial phase coherence at 4 Hz. Attending to the high or low frequency streams lead to a difference in the average phase phase of 4 Hz activity, with the peaks aligned with the attended stream and the troughs aligned with the un-attended stream. After a brief (1.5 hour) training session, task performance increased dramatically in conjunction with stronger entrainment to low frequency tones and decreased distance to target phase. By contrast, we did not observe differences in FFR amplitude for the attended tone stream; however, there was an increase in FFR amplitude from pre- to post-training for both attended and unattended streams. These findings confirm that selective attention can modulate neural phase alignment with auditory streams and that this mechanism can be strengthened by attention training.

1-G -104 Using a V1 model to understand the disordered topography and "complex" pitch cells of A1

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Our understanding of the primary auditory cortex (A1) is still limited because of its disordered tonotopic topography and highly complex response properties. This contrasts with our deeper understanding of the primary visual cortex (V1), which has clearly described retinotopic topography and complex cells. Does the dissimilarity indicate that V1 and A1 are underpinned by different computational strategies? In the present study, we hypothesized that A1 and V1 share a single learning strategy but that they develop in different ways because of their own natural input statistics. Computational studies indicate that the retinotopy of V1 is shaped through learning of natural image statistics, which in turn contributes to the formation of its complex cells. Because V1 shares basic anatomical and genetic features with A1, a similar scenario might explain the seemingly disorganized features of A1. To test the hypothesis, we applied a V1 model called Topographic Independent Component Analysis (Hyvärinen and Hoyer, 2001, Vision Research) to natural sounds instead of to natural images, which were the originally intended input. The original model with natural images produced a smoothly changing retinotopy. In contrast, when we used spectrograms of human voices as input, the tonotopy was disordered in a similar way as reported in A1: neighbouring components did not necessarily have similar frequency

selectivities. Furthermore, because the original TICA explained the V1 complex cells as well as retinotopy, we could investigate the responses of A1 "complex cells" in the learned model. We found that some of them selectively responded to pitch like the missing fundamental cells do (Bendor and Wang, 2005, Nature). The results support the integrative view that A1 and V1 share a single learning rule while receiving their own natural stimuli as input. Additionally, we provided a framework to model the A1 pitch cells as a computational analogue of the V1 complex cells.

1-G -105 Electrocorticographic (ECoG) investigation of auditory predictive coding in the human brain across levels of consciousness

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Experiments exploring auditory local/global deviance (LGD) detection probe the neural bases of sensory awareness. Non-invasive studies show that responses to local deviance (LD) are robust to changes in the level of consciousness, whereas responses to global deviance (GD) are not, and localize this activity to temporal and frontal cortex, respectively. We used ECoG to refine this localization of LGD responses and examine network connectivity before and during induction of general anesthesia. ECoG data were obtained from patients undergoing removal of intracranial electrodes placed to identify epileptic foci. Stimuli were four repetitions of a vowel, followed by the same or different 5th vowel (LD). GD was manipulated by varying the percentage of "same" and "different" patterns. Subjects responded to GD stimuli with a button press while awake. LGD responses were assayed by event-related potentials (ERPs) and high gamma power (HGP). Functional connectivity (FC) was measured as weighted phase lag index. LD effects localized to auditory cortex. GD effects were prominent in frontal and temporal auditory-related areas, had longer latency and reflected subjects' task performance. Increases in HGP were more spatially restricted than ERP effects. Sensitivity to propofol anesthesia was high for GD, moderate for LD in non-core auditory cortex, and low for LD in core auditory cortex. Under waking conditions, short-range FC in the low gamma frequency band was prominent within auditory cortex. FC in alpha band was less prominent but more far ranging. Gamma FC was largely unaffected by anesthesia, whereas alpha FC, especially between distant nodes, was enhanced. Induction of general anesthesia is associated with early suppression of higher-level predictive coding (GD) mechanisms with modest effects on LD mechanisms. Frequency band- and region-specific effects of anesthesia on network connectivity may reflect different effects on feedforward and feedback cortical pathways.

1-G -106 Feedforward and feedback mechanisms governing sensory gating in mice auditory pathway

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Sensory gating is thought to reflect an inhibitory processing component of attention; however despite the long history of characterization of this phenomenon, the neural mechanisms are not clearly understood. We addressed neural mechanisms of sensory gating in head-fixed awake mice using either surface EEG or simultaneous multi-site intracerebral recordings from the inferior colliculus centralsis (ICc), auditory thalamus (medial geniculate nucleus; MGN), primary auditory cortex (Au1) and anterior cingulate cortex (ACC). We used paired tone paradigm with a wide frequency range (white noise) and a

variable inter-stimulus interval (ISI). Analysis of global field power from surface EEG recordings revealed sensory gating up to 2s ISI and pointed to the activation of a large-scale auditory network propagating from the brainstem to the frontal cortices. Our intra-cortical recordings showed a robust attenuation of the LFP amplitude and spike rates of a subset of single neurons immediately after the second tone. The early sensory gating was also reflected in reduced gamma power in the ICc, MGN and Au1 suggesting a feedforward mechanism for attenuation of response from the ICc through MGN to Au1. On the other hand, a delayed increase in beta power in thalamus and delayed firing (~150 ms) of a subset of single neurons in the MGN and Au1 auditory cortex following the first tone suggest a top down mechanism involved in the regulation of sensory gating. This was further supported by a robust enhancement of the cross frequency phase-amplitude coupling between phases of low frequency (~15-20 Hz) LFP in the ACC and amplitude of gamma (~40-60 Hz) power in the ICc. Preliminary results of optogenetic manipulations suggest a causal role for top-down regulation of sensory gating. Taken together, our results suggest a differential contribution of both feedforward and feedback mechanisms in regulating sensory gating.

1-H -116 Pitch and phonetic cues are coded by independent mechanisms in the subcortical auditory system

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Models of complex sound processing based solely on cortical anatomy and physiology have missed a role for the subcortical auditory system in the neural analysis of sounds such as speech and music. A theme across prominent models is that slower, pitch-like cues and faster, phonemic cues are processed by distinct cortical mechanisms (e.g., due to hemispheric differences, Zatorre et al. (1992) Science; Poeppel (2003) Speech Comm). We challenge a fundamental assumption underlying these models: that this dichotomy is the product of cortical analysis. We tested the hypothesis that pitch and phonetic cues are coded by independent mechanisms in the subcortical auditory system in several experiments across species. We used the frequency-following response (FFR), a measure of synchronized subcortical activity, recorded at the scalp in humans and directly from the inferior colliculus in guinea pigs, using speech-like sounds that can be dissociated into pitch (fundamental frequency) and phonetic (formant) features. We first tested the prediction that pitch and phonetic coding vary independently across stimulus manipulations, which was confirmed across rate, noise, and ear of stimulation. Next, we tested the prediction that pitch and phonetic coding vary independently across biological parameters, which was confirmed by establishing distinct developmental trajectories between males and females. Finally, we correlated subcortical and cortical measures of pitch and phonetic coding, showing that the subcortical parsing of pitch and phonetic cues is tied to their cortical decomposition. Together, these experiments show that the acoustic features that convey pitch and phonetic percepts are coded by independent mechanisms in the subcortical auditory system and thus are not simply products of cortical analysis. This motivates a revision of models of sound processing that accounts for the subcortical auditory system. (Supported by NIH, NSF, and the Knowles Hearing Center.)

1-I -123 Altered expression of glutamic acid decarboxylase (GAD1) in the aging human inferior colliculus

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The inferior colliculus (IC) is an important nucleus of auditory pathway. GABA is the major inhibitory neurotransmitter in IC, critically involved in the temporal processing of acoustical stimuli in IC. It is synthesised by decarboxylation of glutamate, and the reaction is catalysed by the key rate-limiting enzyme glutamate decarboxylase (GAD). The previous studies have been performed on the animal models of presbycusis and show the changes in the levels of gamma-aminobutyric acid (GABA) in different nuclei of auditory system with aging. Here, we attempt to find the effect of aging on the transcriptional and translational expression of GAD in human IC by immunohistochemistry and design-based stereology (optical fractionator probe) and quantitative real-time PCR, respectively. We have studied the expression of GAD67 in the human IC (n=27), which were obtained from the mortuary with due clearance from the Ethics Committee and divided into three groups- young age (11-30 years), middle age (31-50 years) and old age (>51 years), where young group was considered as a control group. We saw decreased number and expression of GAD67-immunoreactive neurons in older age groups. The average number of GAD67 immunoreactive neurons was 203388 and 111850 in young and old age groups, respectively. The relative expression (to young age group) of GAD67 mRNA in the middle group was 0.82 and in the old age group was 0.56. This difference in the relative expression was significant (p=0.016). Hence, there is age-related decline in GABA neurotransmitter in the human IC with age and this may be pathogenic of presbycusis.

1-K-117 Phasic pupil-linked arousal reduces decision biases in mice and humans

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The state of the brain changes constantly, profoundly impacting behavior. We recently showed that (i) pupil diameter in mice closely tracks variations in brain state (McGinley et al, Neuron, 2015); and (ii) evoked pupil dilations in humans predicts reduced perceptual choice biases (de Gee et al, eLife, 2017). Here, we directly compare the behavioural correlates of phasic evoked pupil responses in humans and mice performing the same auditory decision task. Mice or humans listened to a sequence of noise tokens followed by a variable-level target tone embedded in a noise token. Humans responded by button press ('yes'/'no' or 'go/no-go') while mice responded by licking for sugar water reward for targets ('go/no-go' only). Building on observations in mice and humans that rapid pupil dilations are associated activity of the noradrenergic system (Reimer et al, Nature Comm, 2016; de Gee et al, 2017), we compared two measures of pupil response: the initial pupil derivative (rising slope) after sound onset, or the change in pupil diameter from before to after trial, including evaluation of the effects of pre-trial pupil diameter.

In both species, large task-evoked pupil responses predicted a reduction in an innate conservative bias (increased tendency to respond 'yes') with no change in sensitivity. Critically, the same effect was present in the yes-no task in humans, in which motor responses were balanced across choices. The bias effect could not be explained by pre-trial 'baseline' pupil diameter or non-linearity (e.g., floor or ceiling effects) of the pupil response. The dynamic modulation of decision bias accounts for a large portion of the behavioural variability, which would appear as random 'noise' without tracking arousal. Thus, pupil dilation can be used as a reference signal that cuts across species and levels of analysis, from single neurons to complex behaviors.

1-I -125 Relationship between speech-evoked neural responses in the auditory sensory system and perception of speech in noise in older adults

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The challenge that speech-in-noise (SPIN) raises for older adults may be due to age-related degradation of phase-locked neural encoding of temporal acoustic cues for speech. These cues include envelope cues that modulate at syllable rates (Slow-rate ENV) and around the fundamental frequency (F0-rate ENV), and temporal fine structure cues (TFS). In this study, the relation between speech-evoked neural responses to these cues and SPIN perception was investigated in older adults. Scalp-EEG responses to a repeated speech syllable and SPIN performances were both obtained under two types of noise: steady-state speech-shaped noise (SpN) and 16-talker babble (BbN). The following measures were extracted from EEGs: 1) theta-band phase-locking values (PLVs) that reflect cortical phase-locked sensitivity to Slow-rate ENV; 2) peripheral/brainstem frequency-following responses (FFRs) phase-locked to F0-rate ENV (FFR-ENV_F0) and TFS (FFR-TFS). Behavioral results showed that SPIN performances were significantly better under SpN than BbN, consistent with previous research. Correspondingly, theta-band PLV was found to be significantly higher under SpN than BbN. Analyses of neural-behavioral correlation found that theta-band PLV was significantly associated with good SPIN performance under SpN, and magnitudes of FFR-TFS at resolved harmonics frequencies were significantly associated with good SPIN performances under both SpN and BbN. Taken together, these results showed that cortical encoding of Slow-rate ENV and peripheral/brainstem encoding of TFS at resolved harmonics are important for extracting target voices during SPIN tasks in older adults, and the differential cortical encoding may serve as the neural mechanism of SPIN performances that vary as a function of noise types. It is suggested that the observed neural signatures associated with SPIN performance could serve as clinical bio-markers for fitting auditory prostheses and developing auditory training paradigms.

1-I -126 Speech and non-speech cortical activation in children with listening difficulties using fMRI

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Around 5% of children experience listening difficulties (LiD), particularly in noisy conditions, but pass standard audiological testing. This magnetic resonance imaging (MRI) study forms part of a larger project assessing whether LiD is due to sensory, cognitive or linguistic processing problems. Bamford-Kowal-Bench (BKB) sentences were presented as normal ?human? speech and ?alien? manipulated non-speech. Manipulations were rotation alone and rotation with vocoding. After listening to a sentence in quiet (under ?sparse? sampling conditions to control for unwanted scanner noise) 6-14y.o. children indicated by button press whether the speaker of the sentence matched the subsequent picture (of human or alien). Contrasts between sentence types allowed dissection of neural representation and skills required to listen and comprehend language: speech (normal vs. rotated/vocoded sentences), phonology (rotated vs. rotated/vocoded sentences) and intelligibility (normal vs. rotated sentences). Sixty-one children completed our MRI protocol. Parent reported listening ability (ECLiPS) showed 33 children experiencing LiD in everyday life. When comparing normal speech with non-speech, cortical activation showed no relationship with composite listening ability (the speech contrast), or between listening ability and processing intonation and phonetic information (the phonology contrast). However, for intelligibility, the left paracingulate gyrus (associated with theory of mind and a designated region of interest) was strongly related to listening ability ($r(61) = -0.58$, $p < .01$) and cognitive ability ($r(61) = -0.37$, $p < .01$), assessed by the NIH toolbox. LiD children were less activated by rotated than normal sentences. Our results suggest that children with LiD process sound, phonetic features and intonation similarly to TD children, but not speech intelligibility.

1-I -127 Sensory precision in tinnitus: a unifying framework for understanding, modelling and treatment?

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Tinnitus affects many people, and hearing loss is its major risk factor. There have been many human and animal studies into the neurobiology of tinnitus, but these have generally been hampered by difficulties distinguishing correlates of hearing loss and its other consequences from those directly associated with tinnitus. There are few if any changes in neural structure, response, activity or chemistry that are plausible singular bases for tinnitus, yet many such changes still appear important. Here, I summarise key evidence and models for the neural basis of tinnitus, along with the mutual exclusivities and contradictions between these. I then introduce the framework of predictive coding, and the concept of precision, and use it to reconcile the disparate neural processes associated with tinnitus. In doing so, I argue that almost all proposed bases for tinnitus share the commonality of increasing the precision of spontaneous activity in the ascending auditory pathway which constitutes a precursor process to perceived tinnitus. I then outline example sequences of events, in terms of Bayesian inference, to illustrate the emergence of tinnitus. This new model provides a reconciliation of previously conflicting evidence and theory, explains why neural activity changes that cause tinnitus need not differ between chronic tinnitus patients and perfectly matched controls, makes a number of testable hypotheses, and opens some new avenues for the study and even treatment of tinnitus.

1-J -138 Extracellular matrix in auditory cortex of adult rodents: impact on remote memory control and learning flexibility

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In our recent study we have revealed that the extracellular matrix (ECM) in auditory cortex of Mongolian gerbils is in control of the behavioral flexibility underlying cognitively demanding reversal learning tasks (Happel et al., 2014, PNAS). This first study implicated a novel function of the cortical ECM as a potential regulatory switch to adjust the balance between stability and plasticity in the adult, learning brain. However, the impact of the ECM on learning-related plasticity, life-long memory re-formation and higher cognitive functions has only started to be examined. Here, we present recent results of intrinsic ECM protein turnover of brevican in auditory cortex of mice (C57BL/6NCrl) correlating with individual auditory learning and remote memory retrieval performance. Using post-training quantitative Western blot analysis, we could demonstrate inherent ECM remodeling during learning, which interestingly correlated with individual learning performance in a Go-NoGo shuttle box discrimination task of rising and falling frequency modulated tones (4-8 kHz vs. 8-4 kHz). Further, enzymatically induced ECM removal in bilateral auditory cortex of mice did not interfere with initial auditory acquisition learning, but improved remote memory retrieval. We will discuss our findings with respect to the relationship between learning and long-term memory retrieval and corresponding endogenous or manipulated ECM protein dynamics with respect to individual behavioral performance.

1-J -139 Imaging neural correlates of learning in awake ferrets using functional UltraSound

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Large-scale functional imaging techniques are part of a fast growing field of neuroscience aiming at understanding whole brain activity. Functional Ultrasound Imaging (fUS) is a new technique giving access to changes in blood flow with a high spatial (~100µm) resolution and sampling rate (500Hz) for a typical imaged section of 1cm wide and 2cm deep, providing a more detailed image than fMRI. Using this technique in awake ferrets, we previously characterized 3D-tonotopic organization of several areas of the auditory cortex, and of deep and small structures like the inferior colliculus or the auditory thalamus. Here, we used fUS to monitor learning-related changes in sound encoding at the level of the primary auditory cortex (A1). A1 tonotopic map have been previously shown to be modified through experience in trained animals (Polley et al., 2006). However, characterizing the precise time-course of these changes across learning proved to be technically challenging and so far unresolved, despite its central role in cognition. We show that training ferrets on a fixed-frequency tone discrimination task elicited changes in A1 tonotopic map that were mainly present in the region coding for the reference sound. The size of these changes was correlated with the amount of water received during each session, a result reminiscent of previous studies on implicit perceptual learning in humans (Seitz et al, 2009). Overall, multi-voxel pattern analysis (MVPA) suggests that these changes improve the discrimination between target and reference sounds.

1-J -140 Behavioural evidence for a relationship between auditory object grouping and speech-in-noise processing

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A persistent problem in hearing impairment (HI) is the fact that peripheral measures do not fully account for outcome variability with speech in noisy real-world environments. We sought to understand the cognitive mechanisms by which listeners detect complex auditory objects (both speech and non-speech) in noisy environments, by examining intermediate cognitive processes as indexed by auditory figure-ground segregation. We hypothesized that the detection of speech in noise (SIN) depends critically on mechanisms for cross-frequency grouping which tap listeners' ability to abstract coherent signals from unpredictable and noisy backgrounds that provide the first stage of auditory object analysis. We investigated whether frequency grouping, indexed by a stochastic figure-ground (SFG) stimulus, predicts SIN ability in normal hearing and hearing impairment. In the SFG single-interval detection task each trial consisted of either background-only or background+figure. The background was heard first and comprised a sequence of random complex tones. On half the trials (figure-present) specific tones remained constant after a transition. The SIN measure adapted the California Consonant Test 4AFC CVC word recognition task, embedding the words in multi-talker babble at two SNR values. We found a significant correlation between SFG and SIN in the normal hearing group (N=75, r=.278, p=.016). General intelligence (indexed by the WAIS) did not correlate with either of the SIN or SFG task scores. A significant correlation between SFG and SIN was also observed in the two groups of hearing impaired

subjects (hearing aid, N=9, r=.727, p=.026; cochlear implant, N=29, r=.550, p=.002). The correlation between auditory object detection (SFG) and SIN may form a vital bridge between peripheral auditory measures and speech outcomes and allow specification of deficits in hearing impaired listeners in a way that is both precise and reflects how people might manage in the acoustic world.

1-J -141 Rhythmic perceptual prior revealed by iterated reproduction

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Probability distributions over external states (priors) are essential to the interpretation of sensory signals. We developed a method to estimate priors for simple rhythms via iterated reproduction of random temporal sequences. Listeners were asked to reproduce random seed rhythms; their reproductions were fed back as the stimulus, and over time became dominated by internal biases, such that the prior could be estimated by applying the procedure multiple times. Our method can be applied irrespective of the participant's musical or cultural background, and is hypothesis-neutral, allowing any possible pattern of results to be detected. We measured listeners' priors over the entire space of two- and three-interval rhythms, examining Westerners with different level of musical expertise as well as members of the Tsimane, a native Amazonian society with very limited exposure to Western music. We found that priors in Westerners showed peaks at rhythms with simple integer ratios, but only those that are prevalent in Western music. Priors were similar for musicians and nonmusicians, suggesting that they are shaped primarily by passive exposure to the music of a culture. Priors in a native Amazonian society also exhibited modes at integer ratios, but were otherwise qualitatively different from priors in Westerners, in ways that are consistent with the structures prevalent in their music. The results were similar for several different modes of reproduction (for example, finger tapping versus rhythmic vocalization of a repeated syllable), but did not extend to the reproduction of spoken phrases, indicating that integer ratio priors are at least somewhat specific to music. Our results are consistent with biological constraints that favor integer ratios, but indicate that any such constraints are strongly modulated by experience. Our method holds promise for characterizing of priors for a range of other auditory domains including phonetics, speech rhythms, and musical melodies.

1-L -151 A perceptual model of timbre in human auditory cortex

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Timbre, or sound quality, is a crucial but poorly understood dimension of auditory perception that is important in describing speech, music, and environmental sounds. The present study investigates the cortical representation of different timbral dimensions. Encoding models have typically incorporated the physical characteristics of sounds as features when attempting to understand their neural representation with functional MRI. Here we take a novel approach and test an encoding model that is based on five perceptual dimensions of timbre to predict cortical responses to natural orchestral sounds. Results show that the perceptual timbre model can outperform other models based on physical characteristics, with the exception of a complex joint spectrotemporal modulation model that performs similarly. In cortical regions at the medial border of Heschl's gyrus, bilaterally, and regions at its posterior adjacency in the right hemisphere, the perceptual timbre model outperforms even the complex joint spectrotemporal modulation model. These findings suggest that the responses of cortical neuronal populations in auditory cortex may reflect the encoding of perceptual dimensions of timbre.

1-L -152 Reverberant sound processing in the auditory system

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In realistic acoustic conditions, sounds are accompanied by many delayed and distorted copies of themselves (echoes or reverberations) arising from reflections off nearby surfaces. Unless the environment is very echoic, our brains cope effectively with reverberation. In contrast, reverberation can cause severe difficulties for speech recognition algorithms and hearing-impaired people. How might the healthy auditory system cope so well with reverberation? A major feature of auditory neurons is their ability to adapt to the sound statistics such as the mean or variance of the sound level. We posit that such adaptive phenomena could reduce the difficulties associated with reverberation. To test this hypothesis, we used a large data set of anechoic natural sounds and a room simulator to generate reverberant sounds. Both anechoic and reverberant sounds were passed through a computational model of the cochlea (cochleagrams). We then trained a linear model to find the best mapping from the reverberant to the anechoic cochleagrams. The transformation learned by the model displayed similar characteristics to the receptive fields of auditory neurons such as narrow frequency tuning and importantly, a temporal profile similar to the adaptation to the sound statistics observed in the auditory system. This model's adaptation-like features showed sound-frequency dependent timescales, consistent with previous experimental data. The timescale of the adaptation-like features also scaled with the amount of reverberation. Hence, the model suggests that the adaptive properties of neurons could be useful in processing reverberant sounds. We are testing the predictions of the model in the ferret auditory cortex using novel electrodes with hundreds of high-density channels (Neuropixels). These electrodes allow us to record from large numbers of neurons simultaneously across all cortical layers, in order to explore adaptation phenomena at both the single-neuron and at the population level.

1-L -153 The cortical representation of sounds with speech-like modulation rates tested with multi-dimensional scaling

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Neural oscillations in auditory cortex entrain to sounds over a wide range of modulation, although there appear to be preferential rates. Two such discrete regimes have been established and investigated, a low-frequency range (< 8 Hz) and a high-frequency range (> ~ 30 Hz). These regimes arguably reflect specialized temporal coding at two clearly distinct timescales in the auditory system. While cortical oscillations do not appear to be similarly robustly entrained by sounds with intermediate modulation rates (8 - 30 Hz), such sounds are perceivable and still give people a clear sense of temporal structure. How does the auditory system track and encode the sounds with mid-range modulation rates? To address this question, we use a match-to-sample task in the context of MEG recording. Participants listened to sounds at five different modulation rates: 4-7 Hz ('theta' sound), 8-12 Hz ('alpha' sound), 13-20 Hz ('beta1' sound), 21-30 Hz ('beta2' sound), and 31-45 Hz ('gamma' sound). While undergoing MEG recording, participants executed a 3-IFC match to sample study with modulation rate as the critical variable. MEG analyses of phase locking as well as classification analyses illuminate the differential encoding: temporal dynamics of sounds can be only read out from theta and gamma band neural responses but not others. Source-space analysis further shows that the prominent entrainment of the theta and gamma bands can be localized early auditory cortex and its surrounding areas. The result

lends support to a discrete multi-scale coding scheme at the cortical level of auditory processing (Poeppel, 2003).

1-L -154 Looming enhanced frequency following responses in rats

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Detecting an approaching object is a crucial ability for animals to survive. From the perspective of evolutionary advantage, it has been proposed that the perception of approaching (looming) sounds is superior to that of receding sounds, which may boost the activation of the defending system in response to the potential risk of predators. Previous studies have demonstrated the perceptual superiority of looming sound over receding sound with behavioral and physiological evidence in both human and animal subjects. However, it remains unknown at what stage of sensory processing does it occur. The auditory brainstem response (ABR) is symbolized by a classic transient deflection followed by a sustained periodic oscillation corresponding to the stimulus frequency termed as frequency following responses (FFRs). Recently, it was revealed by a MEG study that FFRs components may be partially contributed by the cortex. In this study, we presented randomly-interleaved looming tone complexes (1.3-2.6-3.9 kHz) of 8 different durations and their backward version, i.e. receding tone complexes, and recorded stimulus-locked intracranial EEG for measuring FFRs from primary auditory cortex (PAC), lateral amygdala (LA), and inferior colliculus (IC) in anesthetic rats. We found that the FFRs amplitude was overall significantly higher for looming stimulus than that for receding stimulus(PAC: $F(1,13) = 5.490$, $p = .036$; LA: $F(1,13) = 11.735$, $p = .005$; IC: $F(1,13) = 8.260$, $p = .013$), suggesting that the superiority of coding periodic information in looming sound may already emerge at midbrain and be well-preserved in cortex and even limbic system. Specifically, the most remarkable FFRs differences between looming and receding stimulus presented when stimulus duration was 150-ms for PAC ($p = .029$), or 75-ms for LA ($p = .010$), or 200-ms, 250-ms, 300-ms for IC ($p1 = .019$; $p2= .036$; $p3= .013$), which implies that this looming effect may have different neural mechanisms in different brain regions.

1-L -155 On the neural representation of sound categories in human auditory cortex

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Previous fMRI studies robustly observed that sounds of different categories (e.g. voice, speech, and music) preferentially activate localized regions along the superior temporal gyrus and sulcus (STG/STS). While responding maximally to the "preferred" sounds, these same regions also exhibit significant fMRI responses to non-preferred sounds and to synthetic stimuli designed to control for certain acoustic properties. Thus, these regions may be the site of neural processing that transforms low-level (acoustic-perceptual) into higher level (semantic) sound representations. Here, we investigated the nature of these transformations by combining computational models of sound processing and 7 Tesla fMRI. First, we trained a (multiclass) linear SVM to categorize sounds. Sounds (n=288, 1 s, balanced across 6 categories: speech, voice, animal, music, nature and tools) were represented by means of multiple acoustic features (frequency, spectro-temporal modulations, pitch, aperiodicity). The classifier provided a low classification error for all the categories (speech: 0.08; voice: 0.14; animal: 0.20; music: 0.13; nature: 0.06; tools: 0.24). Second, we derived a sound representation model embedding category information from the classifier's weights. We tested this model's ability to predict sound-evoked brain responses using fMRI encoding. Results showed that embedding of category information in the representation model improved the fMRI-based sound identification for all categories, compared to an equivalently complex acoustic model. However, this improvement was greatest for speech, music and nature sounds. These results indicate that: 1) sound categorization can be achieved to a large extent through the simple linear combination of appropriate acoustic/perceptual features and 2) neural representations in cortical regions along the STG/STS are best described through "intermediate" sound representation models embedding acoustical as well as semantic information.

1-L -156 Physiological correlates of the effects of musical scale structures on learning syntactic regularities in melodies

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Humans and other species acquire rule-based sequences implicitly and incidentally very efficiently (Wilson et al., 2015), an ability that may draw back to the crucial need to enhance accurate prediction of future events in sequential signals, such as speech and music (Kleinschmidt & Jaeger, 2015). In music listening, it has been posited that the aesthetic emotion from which music semantics arises is rooted in the fulfillment and frustration of musical events, for which a robust representation of syntactic regularities is essential (Meyer, 2008). Across musical cultures, a few "almost universal" features have been observed and presumed to reflect innate cognitive constraints (Savage et al., 2015). Among those, the asymmetry of musical scales -i.e. the fact that within scales, notes are separated by intervals of different sizes- appears to be the most robust. A recent behavioral study has suggested that asymmetry in musical scales fosters the learning of an artificial finite-state grammar (Pelofi et al., abstract Musical Cultures 2017). Here, using a Markov chain-based grammar (Rohrmeier et al., 2011), we generated reference melodies that displayed transition between notes with high and low probabilities, from one asymmetric and one symmetric hexatonic scale. After an exposure phase of reference melodies, listeners are tested on their ability to detect transitions with null probability contained in alternative melodies, while their brain activity is collected from EEG recordings. We hypothesize that the neural trace of notes onset will reflect the probabilities defined by the grammar in interaction with the structure of the scale. By observing the neural response evoked by high, low or null probabilities of musical events in melodies derived from different scale structures, this study aims to further explore how sophisticated are the predictive coding abilities of the musical brain, while shedding light on the neural underpinnings of universals in music.

1-L -157 Information processing by coordinated neuronal ensembles in the primary auditory cortex

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There is mounting evidence suggesting that sensory stimuli are processed by interconnected populations of neurons. However, most studies of information processing in the primary auditory cortex (AI) involve either single-unit spectrotemporal receptive field (STRF) estimation or paired neuronal correlation analyses, and assume that AI neurons filter auditory information either as individual entities or as pairs. Determining how AI encodes information will require an integrated approach that combines receptive field and multi-neuronal ensemble analyses. To assess multi-neuronal information processing in AI, we performed dense extracellular recordings in rat AI while presenting dynamic, broadband

stimuli. We used dimensionality reduction techniques to identify distinct groups of AI neurons (coordinated neuronal ensembles, or cNEs) that have reliable synchronous activity. We identified cNE events and used them to assess spectrotemporal information processing. Neuronal spikes associated with cNE activity conveyed greater information than spikes that were not associated with cNE activity. For neurons that participated in multiple cNEs, spikes associated with one cNE had receptive field properties that were significantly different from that of spikes associated with other cNEs. These findings challenge the classical idea that AI neurons produce a homogeneous set of spikes that may be equally weighted to estimate a single STRF. Instead, AI neurons can have multiple receptive fields based on associations with different cNEs, with each cNE representing the convergence of thalamocortical, intracortical and top-down inputs into AI. For each AI neuron, equally weighting all neuronal spikes to form a single STRF ignores this enhanced coding capacity. Therefore, by taking into account the stimulus preferences associated with each cNE, we may gain a more complete evaluation of information processing in AI.

1-L -158 Pattern classification of temporal cortex responses to self-delivered sounds and their omissions

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Perception is an active process of interpreting sensory signals. This active process relies heavily on the brain's capacity to formulate predictions about upcoming sensory signals, which are then contrasted against the sensory input. A very important source of sensory prediction is our own motor behavior. It is proposed that a specific prediction of the expected sensory consequences is associated with every motor command. In the present study, we investigated the neural representation of such predictions. Participants learned a motor-auditory association. On every trial, they initiated either a high (6400 Hz) or a low (200 Hz) complex tone by pressing either one of two buttons when prompted by a visual cue every 8.5 s. On 15% of the trials the sound was omitted. High-resolution (1.5 x 1.5 x 2.5 mm voxel size) images of auditory cortex were acquired in a blocked sparse sampling design. When a sound was unexpectedly omitted, we observed activation of early auditory processing areas overlapping with the responses to the sounds. We assumed this activity observed in auditory cortex when predicted sounds are omitted reflects the neural basis of the sound predictions. In order to better understand the neural code of prediction, we performed a multi-voxel pattern analysis. By training the classifier on the sounds and testing on the omissions of the same sounds, we were able to test the hypothesis that the neural representation of the prediction of a specific sound consists of a pattern of activation similar to the sound response pattern in early auditory processing areas. The present findings provide new insights to understand the neural processes underlying the modulation of sensory responses elicited by self-delivered stimulation.

1-L -159 Encoding of irregular amplitude modulations in gerbil auditory cortex

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The encoding of sound envelope by the auditory system is typically studied with periodic amplitude modulated (AM) stimuli. However, the relatively slow modulations found in the sound envelopes of species-specific vocalizations, including speech, are irregular. If neural responses to AM depend only on moment-to-moment changes in amplitude, then responses to periodic stimuli should predict the response to individual AM periods of corresponding duration when they occur within an irregularly fluctuating stimulus. We tested this assumption by measuring the responses of auditory cortex (ACx) neurons to stimuli with envelopes that were modulated with or without a fixed periodicity. The periodic stimulus was 4 Hz AM noise and irregular stimuli contained a range of periods between 1 and 16 Hz, centered at 4 Hz. Preliminary results indicate that, for most ACx units, the response to a standard 250 ms period (i.e., 4 Hz) presented in the middle of each trial was similar, regardless of whether the AM stimulus was periodic or irregular. This observation implies that ACx neurons may not depend on periodicity for encoding envelope. To explore this idea, we designed a second stimulus in which a continuous, dynamic stream of noise transitioned between periodic (AM rates of 2 to 64 Hz) and irregular (periods of 2 to 64 Hz interleaved randomly) sequences. With this stimulus, we can compare the full AM rate tuning functions constructed from periodic and from irregular trials. Taken together, these studies address the relationship between periodicity coding and the representation of the irregular envelopes found in natural stimuli.

Poster Session 2 | Tuesday, September 12, 3:30 PM – 6:00 PM

2-A -4 Behavioral impact of vagus nerve stimulation paired with speech sounds in rats

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Pairing a specific sound with neuromodulator release results in an expansion of the primary auditory cortex (A1) region responding to the paired sound. For example, pairing the speech sounds 'rad' and 'lad' with vagus nerve stimulation (VNS) expands the A1 region responding to and increases the response strength to the paired speech sounds. The behavioral consequences of this enhanced A1 response are currently unknown. In this study, we pair VNS with the presentation of both target and non-target speech sounds during an auditory discrimination task. We hypothesized that VNS speech pairing would increase the rate of discrimination learning. Rats were trained to discriminate between a target and a non-target speech sound. VNS paired rats experienced brief bursts of 0.8 mA VNS simultaneously with the presentation of both sounds. Sham rats were plugged in to the stimulator and performed the same speech discrimination task, but did not receive any stimulation. For both groups, when rats performed the task with 75% accuracy for 2 sessions, they moved on to a novel, more perceptually difficult pair of speech sounds. All rats cycled through multiple speech pairs, and discrimination accuracy and rate of learning were quantified for each discrimination task. Preliminary results suggest that VNS speech pairing alters the rate of discrimination learning. Insights derived from this work could be used to improve outcomes after speech rehabilitation therapies.

2-A -5 Human primary auditory cortex tonotopic map estimated with magnetoencephalography

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Existing fMRI studies propose that the tonotopic organisation of the human primary auditory cortex (PAC) forms a V-shape gradient overlapping Heschl's gyrus, with the lower frequencies being represented laterally and the higher frequencies medially. However, experts disagree when dividing this gradient between the core, belt and parabelt subregion (1). In animal studies, characterisation of neuronal units into subregions can be done considering the high temporal resolution of electrophysiology. In human fMRI studies, short latency variations cannot be studied given the poor temporal resolution of the procedure. In an attempt to further study the human PAC subregions, we developed a novel technique to map the to tonotopic organisation of the PAC using magnetoencephalography (MEG). To reconstruct the PAC tonotopic gradient, eight participants were exposed in the MEG to 10 minute-long multitone stimuli covering the human hearing spectrum. Auditory-evoked brain activity data was then projected onto a 150,000 vertices 3D-reconstructed MRI scan. Reverse correlation analysis was used to obtain spectro-temporal receptive fields (STRF) of each vertex over the superior temporal gyrus, based on previous studies of individual neuron receptive fields. The present study demonstrates that the PAC functional organisation can be precisely determined with MEG. Despite substantial inter-individual differences, we found in the majority of participants low-high-low tonotopic gradients overlapping the superior temporal gyrus. This is consistent with previous findings described by (1), indicating a concordance between fMRI and MEG PAC frequency tuning determination. Due to the high temporal resolution inherent to MEG analysis, we were able to reconstruct PAC STRFs and document additional features distinguishing various PAC subfields. 1. Moerel, M., De Martino, F., and Formisano E. (2014) An anatomical and functional topography of human auditory cortical area Front Neurosci, 8, 225

2-B -11 Distinct sensory and extra-sensory processing differences in two types of deep layer auditory cortex projection neuron

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Neurons in layers (L) 5 and 6 of the auditory cortex (ACtx) give rise to a massive subcortical projection that innervates all levels of the central auditory pathway as well as non-auditory areas including the amygdala and striatum. L5 and L6 neurons feature distinct morphology, connection patterns, intrinsic membrane and synaptic properties, yet little is known about how these differences relate to sensory selectivity in vivo. Here, we performed cell-type-specific single-unit recordings and wide-field calcium imaging from two classes of ACtx L5 and L6 projection neurons; L5 corticocollicular neurons (L5CC), and L6 corticothalamic neurons (L6CT). We first used an antidromic optogenetic "phototagging" approach to isolate individual L5CC and L6CT units on high-density multichannel probes in awake, head-fixed mice. We constructed a bank of complex stimuli by endowing noise tokens with randomly chosen acoustic parameters, and then quantified each neuron's lifetime sparseness. We found that L5CC neurons had a lower lifetime sparseness index, indicative of reduced stimulus selectivity and a broader response distribution than L6CT neurons. Linear spectrotemporal receptive field fits were also able to explain a higher percentage of response variance in L6CT neurons, indicating a higher degree of linearity in their responses when compared to L5CC neurons. Recent studies have shown that an animal's "internal state", as indexed through locomotion or pupil diameter, exerts a powerful influence over ACtx excitability. We expressed GCaMP6s in L5CC and L6CT neurons and noted that bouts of locomotion were associated with opposite effects on the wide-field calcium signal: a decrease in L5CC neurons but a surprising increase in L6CT neurons. Collectively, these studies show that each class of deep-layer projection neuron performs distinct operations on internal and external signals, which likely impart distinct effects on their subcortical targets.

2-B -12 Neurotransmitter receptor transcript expression by neurons and glia in the auditory forebrain: transcriptome-guided cellular phenotyping

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In auditory forebrain research, the layouts and rudimentary wiring diagrams of major brain areas have been generated for key model species. Neuroanatomical efforts are now focused on the characterization of specific circuits to improve the structural bases for functional studies. The identification of the cellular phenotypes that comprise each brain area is foundational to this process. In recent studies, we used next-generation sequencing to profile the coding and long-noncoding transcriptomes of the auditory forebrain (A1, MG) in adult and postnatally?developing mice (Hackett et al, 2015; Guo et al, 2016). One product of this effort was a searchable database profiling expression of ~4700 genes in 237 gene families with relevance to neurotransmission, signaling, plasticity, development and brain structure. Of these, 72 genes in 8 neurotransmitter receptor families were significantly expressed in A1 and/or MG. To identify the neuronal and glial subtypes that express each receptor, and document their spatial locations in tissue sections, we are using multiplexed in situ hybridization to localize receptor transcripts in A1 and MG. The goal is to construct detailed image libraries of cellular phenotypes, based on co-expression of each neurotransmitter receptor with cell-type-specific markers (glutamatergic and GABAergic neurons, astrocytes, oligodendrocytes, microglia). Phenotyping of other gene families will follow. An important application is to increase the specificity of targeting in behavioral, physiological, and connectivity studies by providing detailed maps of the cell-type-specific gene expression patterns. Preliminary data highlighting a sampling of cholinergic and other receptors are presented as examples.

2-B -13 Layer-specific modulation of vagus nerve stimulation on information representation of the sustained activities in rat auditory cortex

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Vagus nerve stimulation (VNS) is a therapy on medically refractory epilepsy. Recent studies reported that neuromodularoty effects of VNS also improve cognition, yet its neural mechanisms remain to be elucidated. Previously we demonstrated that the receptive fields and adaptation of transient activities in auditory cortex were modulated by VNS in layer-specific manner, raising a hypothesis that the change of sensory cortical representation mediates such cognitive improvements. Here, we investigated how VNS affect representation of sustained activities in rat auditory cortex by using machine learning. A microelectrode array with 96 recording sites recorded local field potentials (LFPs) from supragranular, granular or infragranular layer of the rat auditory cortex under isoflurane anesthesia. We presented long-lasting pure tones (30-s duration, 60 dB SPL) with five frequencies (8, 10, 13, 16 and 32 kHz), which were repeated 7 times in a pseudorandom order and interleaved with a 30-s silence. After the first recording, VNS was given in a series of electrical pulses lasting 30 s with inter-stimulus-interval of 300 s, during which the second recording was performed. The recorded LFPs were bandpass filtered in five bands (theta, 4-8 Hz; alpha, 8-14 Hz; beta, 14-30 Hz; low-gamma, 30-40 Hz; high-gamma, 60-80 Hz), and we extracted 70 samples of phase locking value (PLV). Then sparse logistic regression was applied to decode the test frequency from these samples of PLV patterns, and we obtained decoding accuracy in the decoding from the test data. As results, higher decoding accuracies were achieved in the granular and infragranular layers than the supragranular layer, indicating ambiguous sound representation in the supragranular layer. After VNS was applied, decoding accuracy improved in the supragranular and granular layers, and deteriorated in the infragranular layer, indicating layer-specific effects of VNS on sound representation of the sustained activities.

2-B -14 Cortical plasticity with bimodal listening in children with asymmetric hearing loss

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This longitudinal study aimed to identify in children with asymmetric hearing loss: 1) abnormal cortical preference for their better hearing ear at initial cochlear implant activation; and 2) plasticity of the auditory cortices after chronic cochlear implant stimulation in the deaf ear and continued acoustic hearing in the other ear (bimodal listening). Participants included 12 children with asymmetric hearing loss (mean±SD difference = 41.1±45.3 dB) who were implanted at age 9.4±5.0 years. Many children had residual low frequency hearing in the implanted ear (250Hz: 44.5±42.1, 500Hz: 65.0±44.5 dB HL). Multi-channel EEG was measured at initial implant use (5.8±3.2 days) to achieve the first aim and then again after 11.1±4.4 months of bimodal use to achieve the second aim. Monaurally presented stimuli consisted of 36ms trains of acoustic clicks/biphasic electric pulses presented at 1Hz. The time-restricted artifact and coherent source suppression (TRACS) beamformer was used to locate sources underlying peak amplitudes of cortical responses. Results indicated consistent activity from the non-implanted ear but significant implant-driven changes to the auditory cortices. Unexpected initial activity evoked by the newly implanted ear strongly lateralized to the ipsilateral auditory cortex which contributed to a significant aural preference for the implanted ear in some children. With ongoing bimodal stimulation, ipsilateral responses from the implanted ear decreased resulting in expected lateralization to the contralateral auditory cortex and no clear aural preference for one ear. Findings suggest that bimodal use in children promotes expected organization of bilateral auditory cortices. Despite these positive results, most recorded changes were isolated to pathways stimulated by the cochlear implant, potentially reflecting an abnormal independence of the bilateral pathways which may, in turn, have consequences for binaural integration in these bimodal listeners.

2-C-22 Optogenetic activation of the claustrum induces divisive normalization of tone evoked responses in the auditory cortex

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The claustrum is a thin sheet of neurons located deep in the brain of all mammals. Enclosed between the insular cortex and the striatum, it has been shown to have widespread reciprocal connections with sensory cortices, frontal areas, as well as sub-cortical nuclei. Its delicate anatomy renders the claustrum largely inaccessible, preventing functional research. We have recently proposed that by regulating cortical gain, the claustrum may suppress task-irrelevant sensory stimuli and support attention (Goll et al. 2015). To address this hypothesis and uncover the function of the claustrum, we established a novel genetic method to selectively target claustral neurons in mice. By injecting cre-inducible anterograde and retrograde viral tracers, we mapped the connectivity of these cells, and found that they display the characteristic widespread connectivity of the claustrum (Atlan et al. 2016), validating our system. Notably, we found reciprocal connectivity between the claustrum and the auditory cortex, raising the question whether the claustrum can affect auditory processing. To assess this, we played an array of logarithmically spaced pure tones (3-70 kHz) to anesthetized mice, and optogenetically activated claustrum neurons or processes while performing loose-patch recordings or bulk calcium photometry, respectively, in the auditory cortex. Firing rates in most of the affected single cells were selectively suppressed at their preferred frequency. Population calcium activity, however, revealed that claustral activation drives divisive normalization, demonstrating that the claustrum is capable of broadly desensitizing cortical responses, while maintaining their baseline tuning. Our work serves as the first functional perturbation of the claustrum, demonstrating that it acts as a regulator of cortical excitability, and implicating it as a novel target for treatment in disorders of attention and perception, such as autism, schizophrenia, and ADHD.

2-C-23 Changes in audiovisual word perception during mid-childhood: an ERP study

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Speech-in-noise (SIN) perception is significantly facilitated by seeing the talker's face. However, the degree of such facilitation depends on a variety of factors, including age, with even adolescents being less effective than adults at using visual speech cues. The specific neural processes engaged during the observation of language-related articulation, their developmental trajectories, and relationship to better SIN perception are not yet understood. In this study, we examine behavioral and electrophysiological responses of younger (8-9 years of age) and older (11-12 years of age) children as well as adults during an audiovisual word matching task and relate them to SIN and lip-reading abilities. On each trial, participants first heard a word and, after a short pause, saw a speaker silently articulating a word. In half of trials, the articulated word matched the auditory word (congruent trials), while in another half, it did not (incongruent trials). Participants specified whether the auditory and the articulated words matched. We compared groups on sensory ERPs elicited by the onset of visual stimuli (C1, P1, and N1) as well as on later cognitive ERPs elicited by articulatory movements--namely, N400 to incongruent articulations and late positive complex (LPC) to congruent articulations. Lastly, we examined the relationship between ERP measures of visual speech processing and the degree of benefit from the presence of the talker's face on an SIN task. Preliminary analyses show that, at least in children, both early sensory and later cognitive visual ERPs can account for a significant amount of variability in SIN accuracy. Results also show that N400 and LPC reflect different neural processes with distinct developmental trajectories. Namely, LPC to congruent articulations indexes word recognition and is adult-like by 11-12 years of age, while N400 to incongruent articulations indexes phoneme to articulation matching and continues to develop during teen years.

2-D -45 Linking neuronal response properties to a decision variable in the auditory cortex

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The sensory information from the external world - the sensory evidence - is an essential component of the decision variable upon which an animal can make qualified decisions. In this study, we asked what aspect of the neuronal response to sensory evidence is a crucial component for the decision making in a simple discrimination task. We trained mice in an auditory go/nogo task, where the animals had to lick a drop of liquid as reward to a pure frequency tone (the go tone), and had to restrain from licking when hearing another frequency tone (the nogo tone). The task difficulty was then increased by bringing the nogo tone closer in frequency to the go tone. Response properties of neurons in the primary auditory cortex (A1) were determined using extracellular electrophysiology and correlated to behavioral performances. We found that the overlap of the population of neurons responding to the go and nogo tones was directly correlated with the discriminability capability of the mouse. We then manipulated the receptive field properties of A1 neurons by adding a continuous white noise to the sound stimulation. This manipulation increased the neuronal selectivity to a narrower frequency band. At the behavioral level, adding white noise surprisingly increased the discriminability of tones only if their frequencies were close to each other. We asked if this improved discriminability was related to modifications of A1 neuron response properties, or whether white noise affected decision-making via a pathway bypassing A1. We answered this by increasing frequency selectivity of A1 neurons by optogenetic manipulation of parvalbumin interneurons. At the behavioral level, this optogenetic manipulation had the same effect as the white noise: it improved discrimination of tones close in frequency. Our results indicate that response properties of A1 neurons, and particularly their selectivity to a certain frequency band, are part of the information the mouse uses to make decisions.

2-D -46 Modification of the adult rat tonotopic map through passive sound exposure impairs performance on a tone discrimination task

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[1]McGill University

After maturation, the rat auditory cortex exhibits a stereotypical tonotopic map that remains stable throughout life. However, housing adult rats in broadband white noise has been found to have a profound plasticity-inducing effect on this map. The current study used a behavioral paradigm to test the hypothesis that passive noise exposure can be used as a tool to improve learning in adult rats. First, we showed that a two-week exposure to noise followed by a one-week exposure to 7kHz tone pips was sufficient to produce an overrepresentation of the 7kHz frequency region in the tonotopic map of a group of adult rats. Next, we trained one group of exposed and one group of non-exposed rats on an adaptive tone discrimination task where the target tone was 7kHz. In previous paradigms with this design, learning was associated with an overrepresentation of the target tone in the tonotopic maps of trained rats. Thus, our expectation was that exposed rats would have an advantage on this task because of the induced early overrepresentation of the target tone. Contrary to our expectations, however, we found that exposed rats had poorer behavioral performance. Despite responding to the target tone at the same rate as non-exposed rats, they were not able to suppress their response to non-target tones. This performance was accompanied by electrophysiological changes in auditory responses that also demonstrated reduced discriminability of the overrepresented tone. These results suggest that passive exposure to noise can lead to maladaptive plastic changes in the auditory cortex that can affect performance and behavior.

2-D -47 Relating speech intelligibility to neural entrainment of the speech envelope

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Introduction: The envelope of a natural speech signal can be decoded from the EEG. The correlation between the decoded signal and the original envelope yields a measure of neural entrainment to the envelope. As the speech envelope is a primary cue for speech intelligibility, we hypothesise that its neural representation is a prerequisite for speech intelligibility. It can therefore be used to predict speech intelligibility if most other influencing factors can be accounted for. We will review a number of studies from our lab in which we investigated the interrelations between speech intelligibility, neural entrainment of the envelope, listening effort, and attention. Methods: We measured the EEG evoked by running speech masked by speech spectrum weighted noise at a number of signal-to-noise ratios (SNR). Behavioural speech intelligibility was measured using standardised audiometric materials and subjective ratings. Listening effort was measured using a dual-task paradigm. Attention was manipulated by introducing various distractions and estimated over time using a measure of spectral entropy of the EEG. Results: When investigating the time course of neural entrainment to natural speech, we found a small decreasing trend. Under controlled circumstances, behaviourally measured speech intelligibility correlated well with a measure of intelligibility derived from the SNR versus envelope entrainment function. The results were not strongly influenced by the level of attention for short integration windows of the decoder. The correlation between SNR and envelope entrainment was not improved by including a measure of listening effort. Conclusions: By carefully selecting speech materials, procedures and signal processing methods, we were able to find a correlation between speech intelligibility and neural entrainment of the speech envelope. This has applications in objective audiometry and closed-loop auditory prostheses that adapt their function to an individual user.

2-D -48 Circuit processing in rodent auditory cortex underlying auditory learning in cognitively demanding tasks

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The fundamental role of auditory cortex in learning auditory associations and in formation of corresponding memory traces is well known. However, the knowledge about the distinct cortical circuit mechanisms underlying learned auditory complex behaviors is still limited. In a recent study, we proposed a recurrent feedback gain circuitry between auditory cortex and thalamus that is under dopaminergic control and promotes the detection of behaviorally important stimuli (Happel et al. 2014). In this study, we chronically recorded laminar LFP from primary auditory cortex (A1) of Mongolian gerbils (Meriones unguiculatus) over the course of several weeks, while animals successfully performed multiple contingency reversals of a frequency discrimination task in a shuttle-box paradigm. We have used methods for a trial-wise estimation of the choice probability (Deliano et al., 2016) in order to regress the behavioural data outcome against single-trial current source density (CSD) parameters. Our goal is to better understand layer-dependent processing modes in A1 underlying the behavioral outcome. This methodology enables us to further investigate the long-term layer-depended adaptations of the cortical processing in the context of different forms of learning (detection/discrimination/reversal) and during task-dependent plastic reorganizations of synaptic circuits. Finally, the newly developed approach allows us to discuss causal links between cortical processing modes in sensory cortex, as recurrent feedback gain, and cognitively complex forms of decision-making and perceptual stages during learning.

2-D -49 Pupil dilation responses to violation but not emergence of auditory patterns

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Understanding which aspects of the sensory environment automatically attract attention is key towards uncovering the features of the dynamically changing sensory environment that our brains are wired to treat as significant. An emerging hypothesis suggests that regular， predictable, sensory patterns are perceptually prioritized so as to focus attentional resources on stable features of the environment. Here we address this issue with pupillometry, which constitutes, arguably, the most direct measure of the salience of a stimulus (Liao et al., 2016). Participants listened to sequences of abutting 50ms tone pips (adapted from Barascud et al, 2016) which contained transitions from random to regularly repeating frequency patterns and vice versa. To ensure that participants paid attention to the auditory stream but not to the transition per se, they were instructed to detect occasional silent gaps within the sequence. This task encouraged attentive listening but was independent of sequence regularity. We found that even though both transition directions (regular-to-random and random-to-regular) are clearly detectable behaviorally and both evoke strong MEG (Barascud et al, 2016) and EEG (Southwell et al, 2016) responses, pupil dynamics appear to only respond to pattern changes manifested as a violation of regularity. Stimuli characterised by an emergence of a pattern evoke no measurable pupil response. This is interpreted as a failure to engage the fight-or-flight system and in turn leading to the conclusion that our brains have evolved to attribute salience to a violation of an established context and not to the emergence of a new pattern.

2-D -50 Activity in the ferret auditory cortex during localisation and categorization judgements of multisensory stimuli

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Auditory perception takes place in complex multisensory environments, in which interactions across senses may result in enhanced or degraded behavioural responses to acoustic events. To explore the relationship between behaviour and neural activity in such scenarios, we recorded the activity of primary auditory cortical neurons when animals were making localization and categorization judgements of multisensory stimuli. Ferrets trained by positive operant-conditioning to localize unisensory (auditory or visual) and spatiotemporally coincident auditory-visual stimuli showed more accurate and faster responses to multisensory than unisensory stimuli. Similarly, the animals learned to correctly categorize bimodal stimuli on the basis of the spatial congruency of their unisensory components. Electrophysiological recordings were made bilaterally in the primary auditory cortex during behavioural testing, as confirmed histologically at the end of the experiment. Out of 509 single units that exhibited excitatory responses to acoustic stimulation, 16% produced responses that were modulated by visual stimulation. Statistical models of the driving activity in cortical neurons indicated that the priors, intensity and location of the stimulus are the main factors that influence the neuronal firing rate. On the other hand, the presence of simultaneous visual information in the case of the localization judgments and the category identity in the case of the categorization experiment did not contribute significantly to their firing rate. In addition, although higher correct scores in the behaviour were associated with lower spontaneous firing rates and contralateral higher evoked firing rates, that can be explained by the stimulus properties. These results suggest that activity in the primary auditory cortex is not significantly correlated with multisensory spatial integration or categorisation, and that the neural basis for these behaviours is likely to reside elsewhere in the brain.

2-D -51 Linking tonotopy to myeloarchitecture: an in-vivo MRI investigation of the association between frequency selectivity and R1 relaxation rates in the human auditory cortex

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Cortical auditory fields have traditionally been defined in mammals using highly detailed and labor-intensive functional (in-vivo electrophysiological) and structural (ex-vivo myelo/cyto-architecture and tracer-based connectivity) measures, with results summarized qualitatively across a small number of animals. By contrast, human neuroimaging (MRI) operates at a much coarser spatial and temporal resolution, and only recently has allowed for estimation of in-vivo macroscopic cortical myelination. However, by acquiring multiple measures from the entire cortex of many living subjects, human MRI allows us to reveal novel and subtler spatial relationships between different functional (e.g. tonotopic) and anatomical (e.g. myeloarchitectonic) characteristics in auditory cortex, critical for understanding the basic developmental principles of cortical organization. Here, we used high-resolution multiparameter mapping and an attentionally-demanding tonotopic mapping procedure using bandpass-filtered natural sounds to estimate myeloarchitectonic and best frequency and tuning width in 59 young healthy young adult humans. The cortical-surface-curvature-registered cross-subject average showed consistency with previously published myelin and tonotopic maps, as did the tonotopic gradients within presumptive auditory core. Best frequency and tuning width showed consistent relationship across subjects; spatial gradients in the degree of frequency selectivity were also reliably associated with gradients in myelin-related quantitative 1/T1 relaxation rates along the medial and lateral aspects of auditory-related cortex. Profound individual differences were found in topographic organization within both early auditory areas and strongly tonotopic lateral regions. Even accounting for attentional effects and measurement error, cross-run comparisons and retest data, these results suggest that there is more individual variability in auditory topography than has been generally acknowledged.

2-D -52 Separating stimulus-driven and entrained neural responses using musical rhythms

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Interest in the role of neural entrainment in perception and cognition is on the rise. However, the nature of the neural signals observed in response to rhythmic auditory stimuli is still a matter of debate. Specifically, it is unclear the extent to which these neural responses truly reflect entrainment of endogenous neural oscillations, or may instead reflect the superposition of transient neural responses evoked by patterned stimulus onsets. Here, we attempted to tease apart these two possibilities by measuring electroencephalography (EEG) during listening to musical rhythms. We independently manipulated the strength of the perceived beat and acoustic properties of the tones making up the rhythms (tone duration, onset/offset ramp duration) in order to systematically change the energy present in the spectrum of the stimulus envelope at beat-related frequencies. We then predicted the strength of neural responses at beat-related frequencies from stimulus energy (reflecting linear responses to the acoustic stimulus structure) and perceived beat strength (reflecting nonlinear resonance over and above stimulus-driven responses). We found that, at nested beat frequencies, neural responses were more strongly predicted by the percept than by the stimulus spectrum. This

finding suggests that neural responses to musical rhythms reflect more than a superposition of transient responses evoked by individual tones, and thus may indicate entrainment of neural oscillations and nonlinear resonance at beat-related frequencies.

2-D -53 Auditory-motor temporal recalibration: relationship between illusory reversal of action and sensation with auditory semantic representations

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When the sensory-motor system is habituated to a specific temporal delay between action and sensory consequence, sensory events presented with a shorter delay are perceived as being presented before the motor act (Stetson et al., 2006; Timm et al., 2014). This is called temporal order reversal effect (TORE). We studied the robustness of TORE in the context of different auditory objects to test if the meaning of a sound object can affect the strength of this effect. 39 adult participants were habituated to a sound being presented either immediately (realtime) or 200 ms (delayed) after they pressed a button during an adaptation phase. A test phase followed this habituation. After each test trial participants had to judge whether the sound they just heard preceded or followed their motor act while delays were presented between ± 270 ms after their button press. Both adaptations and tests (realtime and delayed) were performed in two sound categories; using either an action related (AR) or a non action related (NAR) sound. For each test phase responses were modeled unto a psychometric response curve to derive the point of subjective simultaneity (PSS). The extent of the TORE corresponds to the difference in subjectively perceived simultaneity as derived from the psychometric response curve for the delayed and the realtime condition. For both sound categories, we found a main effect of the delay in PSS and in reaction time (RT). TORE was present for both sounds indicating that participants judged that more sounds were presented before the motor act after delayed sensory-motor recalibration. We also observed that across subjects the extent of TORE correlated with RT in the AR sounds but not in the NAR sounds suggesting a more heterogeneous relationship between the TORE and RT for AR sounds. Therefore, we conclude that the TORE can be induced using various auditory semantic representations and even AR sounds.

2-D -54 Perceptual alternation in auditory streaming as an evidence accumulation process

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Subjects report when listening to brief pure tones, alternating high (A) and low (B), in sequences ABA_ABA_.... spontaneous switching between two percepts: "integration" (Int), a single, coherent stream, the galloping pattern and "segregation" (Seg), two simultaneous distinct streams: A_A_ and B___B___. This triplet stimulus is considered a paradigm for auditory perceptual grouping, stream formation, and for the cocktail party problem. The initial percept is typically Int while Seg "builds up" with a time course of seconds. It is said that Int is the default while evidence accumulates for the switch into Seg and thereafter, during long presentations, irregular alternations occur between Int and Seg. The psychometric build-up function (from trial-averaging) depends on the difference in A-tone and B-tone frequency, DF, is typically monotonic, and percept durations are gamma/lognormal distributed. Recordings from primary auditory cortex (area A1) of monkeys listening to triplet sequences have been used to construct neurometric functions from a signal-detection model (Micheyl et.al, 2005) that resemble psychometric functions. However, that model predicts neither realistic mean percept durations nor percept durations that are gamma-like distributed (Pressnitzer & Hupe, 2006). We developed an accumulation model in the form of a multi-layer feedforward network with neural-like components. The model accepts A1 neuronal responses (including variability) as input. Each B-tone is classified as Int or Seg by binary units (each samples a subset of A1 neuron spike counts). A noisy accumulator increments its activity based on the classifier output, representing growing evidence against the current percept. A switch and reset occur when a threshold is reached. The model generates build-up functions as well as percept durations with statistics that match data from our behavioral experiments (15 subjects, 30 sec trials) for DF=3,5,7 st.

2-D -55 Effects of feature selective attention in single neurons in primary and belt auditory cortex

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Realistic sensory environments usually contain a lot of information irrelevant to what an animal needs to make a behavioral judgement. Feature selective attention can help sift through this competing information by selecting the relevant sensory features. How attention affects sensory representations throughout the auditory cortical hierarchy is poorly understood. Therefore, to study how auditory encoding is influenced by attention in single neurons in two different stages of the auditory hierarchy, we measured activity in single neurons in primary auditory cortex (A1) and middle lateral auditory belt (ML) in rhesus macaques while they performed a feature selective attention task. In this task, monkeys attend to one of two features of the same sounds: (1) amplitude modulation and (2) carrier bandwidth. We found single neurons in ML, but not A1, showed effects of attention on amplitude modulation sensitivity. This suggests that higher areas in the auditory cortical hierarchy are more greatly influenced by attention.

2-D -56 Streaming music in the brain: Investigating the top-down modulation of auditory stream segregation and integration with polyphonic music

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Listening to polyphonic music very well exemplifies the interaction between bottom-up and top-down mechanisms involved during real life hearing. Typically, music is perceived by integrating the sounds from the various instruments, however, under the control of attention, it is also possible to selectively attend to any one of the instruments. Here, we investigated the neural correlates of top-down modulation of auditory stream segregation and integration using high spatial resolution (1.2 mm) functional MRI at 7 T, with a behavioral paradigm providing control over the listener's locus of selective attention to scene elements for multi-instrument music. During scanning, 9 nonmusicians were presented with custom composed polyphonic music stimuli (28 s duration) comprising two distinct timbres (Bassoon and Cello). Listeners were cued to attend one of the instruments or the aggregate and detected triplet patterns (i.e. rhythmic modulations) present either within one of the voices, across voices, or not present. fMRI data were analyzed combining independent component analysis (ICA) and multivoxel pattern analysis (MVPA). Data were divided into three splits and ICA was performed per split using as input the response estimates of those voxels showing significant activation. For each split, an independent component representing a subject's frontal-temporal network could be identified stably within and across subjects; this was selected as ROI for subsequent classification. MVPA results indicated that the attention condition could be decoded above chance (2000 permutations, 95th percentile) during the pre-triplet stimulus section. These results indicate that a listener's attentional locus can be decoded from fMRI response patterns in the fronto-parietal attention network even when the stimuli are complex polyphonic musical pieces. With further analyses we are investigating the consequences of these top-down effects on the auditory cortical representations of music.

2-D -57 The effect of musical experience on the organization of neural stimulus selectivity in human auditory cortex

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Speech and music perception are core functions of the human auditory system, but we know little about the neural systems that process these complex auditory signals. While speech-selectivity is known to characterize regions of non-primary auditory cortex, clear neural selectivity for music has only recently been demonstrated (Norman-Haignere, Kanwisher, & McDermott, 2015). This study measured fMRI responses to a wide variety of natural sounds and modeled the response of each voxel as a weighted sum of canonical response patterns to the sound set ("components"). Six components explained 80% of the replicable variance in the responses across auditory cortex. Four of these components reflected selectivities for acoustic features of the sounds (e.g. frequency, spectrotemporal modulation), and two showed selectivity for the high-level categories of music and speech. When these speech- and music-selective components were projected back onto the brain, they concentrated in non-overlapping regions of non-primary auditory cortex, and their anatomical distribution was similar across subjects. This new method for parcellating neural stimulus selectivity allows us to ask many questions. Here, we examine the extent to which this component structure is altered by experience. Specifically, we report the extent to which musical training affects stimulus selectivity in auditory cortex by comparing the anatomical distribution and selectivity of response components in expert musicians versus control participants with minimal musical training.

2-D -58 Multivariate fMRI and MEG responses to vocalizations reveal temporally and spatially segregated representations of emotion categories and dimensions

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Different views on the representation of emotional events emphasise either categories (e.g., anger) or continuous dimensional attributes (e.g., arousal). The extent to which these account for cerebral representation is largely unknown because of a lack of direct comparisons. We addressed this question by analysing fMRI, MEG, and behavioural data collected while participants (n=10) listened to a homogeneous set of nonverbal affective vocalisations (800ms; n=39 per speaker, one female, one male) generated by morphing between 5 emotions (anger, fear, disgust, pleasure, neutral) to cover a range of categories and dimensional values. Data for each individual was collected across 11 sessions: 8 fMRI/MEG (alternated; task: one-back repetition detection), 2 for ratings of perceived stimulus dissimilarity, and a last one for three measures of perceived affect: (1) emotion categorisation, (2) arousal ratings, and (3) valence ratings. Group-level representational similarity analyses (RSA) contrasted the ability of these categorical or continuous affect measures to account for the multivariate fMRI and source-level MEG response patterns across stimuli (spatial and spatio-temporal searchlight, respectively). Behaviourally, perceptual dissimilarity between stimuli was accounted for by both categories and dimensions but with stronger dependence on categories. MEG-fMRI RSA confirmed that the auditory cortex (AC) represented both categories and dimensions but with earlier selective representation of categories (~100ms) than arousal (~200ms) or valence (~600ms). Selective affect representations also emerged outside the AC: emotion categories in the left inferior frontal gyrus, arousal in the right amygdala (onset at ~200 ms for both) and valence in the right pSTG (~600 ms). Overall, we show that the human brain codes both the categorical structure and dimensional attributes of vocal emotions but in temporally and spatially distinct representations. PB, JG: joint senior.

2-D -59 Cortical responses reveal individual differences in speech-in-noise understanding ability

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Even among young normal hearing people, there is great variation in the ability to understand speech in noisy real-world settings. The purpose of this study is to investigate neural correlates of individual differences in speech-in-noise understanding. Previous studies suggest that successful understanding of speech involves a close interplay between auditory and inferior frontal cortices as acoustic features extracted from speech are lexically processed. This cortical pathway was tested in thirty young adults with normal hearing thresholds during a 4AFC CVC word-in-noise recognition task. Our cortical surface-constrained EEG source analysis revealed that speech-related responses in auditory cortex were earlier and greater in listeners with better performance than in low performers. Better performance was also linked with left hemisphere-dominant prefrontal activity following the auditory cortex response, whereas low performers demonstrated prolonged right hemisphere-dominant prefrontal activity. This result confirms the general processing pattern of speech perception connected to the left prefrontal cortex. We also report that degraded speech-in-noise understanding is related to weak auditory cortex responses and abnormal balance of prefrontal lobe activity.

2-D -60 Steady state-evoked potentials reflect context-induced perception of musical beat in an ambiguous rhythm

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Synchronization to rhythmic stimuli is an everyday experience, whether it is exercising to the beat of music, dancing salsa, or rocking a baby to sleep. Commonly, humans synchronize their movements with the frequency of the beat (a quasi-isochronous pattern of prominent time points). In addition, Western music is thought to have a metrical hierarchy, which results in stronger (downbeat) and weaker (upbeat) events. Previous research has shown that the intended beat periodicity of a rhythmic stimulus can be observed in periodic neural activity; however, the extent to which this reflects robust perception of musical rhythm versus purely stimulus-driven activity is unknown. We used electroencephalography (EEG) to investigate whether steady state-evoked potentials (SS-EPs, the electrocortical activity from a population of neurons resonating at the frequency of a periodic stimulus) arising from auditory cortex reflect beat perception when the physical information in the stimulus is ambiguous and supports two possible beat patterns. Participants listened to a musical excerpt that strongly supported a particular beat pattern (context), followed by an ambiguous rhythm consistent with either beat pattern (ambiguous phase). During the final probe phase, listeners indicated whether or not a superimposed drum matched the beat of the ambiguous rhythm. We found that participants perceived probes that matched the beat of the context as better fitting the ambiguous rhythm, compared to probes that did not match the beat of the context. We also found that SS-EPs during the ambiguous phase had higher amplitudes at frequencies corresponding to the beat of the preceding context. These findings support the idea that SS-EPs arising from auditory cortex reflect perception of musical rhythm and not just stimulus encoding of temporal features.

2-D -61 Neural responses in auditory cortex predict motion processing thresholds in deaf and hearing individuals

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Lifelong auditory deprivation can lead to increased visual sensitivity (Bavelier et al., 2006), particularly to motion in the far periphery (Codina et al., 2016; Lomber et al., 2010). This is where sound may confer the greatest advantage to hearing individuals, acting as an 'early warning system'. FMRI studies have reported cross-modal activation in auditory cortex in deaf individuals to visual motion; however, previous neuroimaging studies do not capture far-peripheral motion signals (Scott et al., 2014; Fine et al., 2005). Auditory cortex comprises architectonically distinct regions with potentially different functional roles and response levels (Scott et al., 2014), but the relationship between activity in these auditory regions and visual performance in deaf humans is unclear. Our study compared activation in different human auditory regions and their relationship with visual performance in a far peripheral motion task in deaf and hearing human adults. Sixteen congenitally deaf and 16 hearing controls underwent fMRI scans, viewing wide-field (0-72°) optic flow coherent and incoherent dot motion. Neural responses were extracted in three auditory regions spanning anterior to posterior superior temporal cortex: Te1.2 (Juelich atlas, Morosan et al., 2001), Heschl's gyrus and the planum temporale. Participants also completed a far-peripheral global motion discrimination task outside of the MRI scanner. In deaf individuals, coherent, but not incoherent motion led to activation or significantly less suppression of auditory regions. In hearing subjects both coherent and incoherent motion suppressed auditory responses below baseline. Responses in anterior auditory area Te1.2 predicted motion coherence thresholds in all participants - greater suppression was correlated with better performance in the far-peripheral global motion discrimination task. This suggests that activation of auditory regions may not necessarily benefit deaf individuals in certain visual tasks.

2-D -62 A three-dimensional digital atlas of the mustached bat brain

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Substantial knowledge of auditory processing within mammalian nervous systems emerged from neurophysiological studies of the mustached bat (Pteronotus parnellii). This highly social and vocal species retrieves precise information about the velocity and range of its targets through echolocation. Such high acoustic processing demands were likely the evolutionary pressures driving the over-development at peripheral (cochlea), myelencephalic (cochlear nucleus), mesencephalic (inferior colliculus), diencephalic (medial geniculate body of the thalamus), and telencephalic (auditory cortex) levels of the auditory system in this species. Auditory researchers stand to benefit from a three dimensional brain atlas in this species, due its unique anatomy and substantial contribution to auditory neuroscience. Here, we used a magnetic resonance imaging (MRI) scanner with a high magnetic field

strength (9.4 Tesla) to acquire detailed T2-weighted 3D-RARE scans [(59 x 63 x 85) μm^3] and Super-Resolution Reconstructed Diffusion Tensor Imaging (SRR-DTI) scans [(78) μm^3] of a male mustached bat's brain. The delineation of the subcortical auditory system and other indicative gray and white matter structures was facilitated by a combination of high image resolution, hypertrophy of auditory nuclei, and detailed histological records. This atlas will soon be freely available from our website and can simplify future electrophysiological, microinjection, and neuroimaging studies in this species.

2-F -89 The effect of bilingualism on syntactic and semantic recognition in children
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Bilingualism is known to greatly affect cognitive function of children. This study is the first to look at the effect of bilingualism on semantic and syntactic sentence processing in Mongolian-English bilinguals aged 3-21, where English is a second language (L2). Methods: quantitative electroencephalography was used to record event related potentials (ERP) in Mongolian monolinguals and Mongolian-English bilinguals using WEEG32 (Laxta, Korea). Syntactically and semantically correct or anomalous sentences in native language (Mongolian) were presented to volunteers during the recordings, one word per time. Independent component analysis was used to reject artefactual components on EEGlab toolbox of Matlab software. Results: when ERP peaks such as LAN (left anterior negativity), N400 and P600 were assessed, main differences in the peak amplitudes and locations between monolinguals and bilinguals were observed in younger children aged 6 and less. Early age of L2 initiation have also significantly affected the expression of peaks showing higher amplitudes in monolinguals. However, duration of L2 exposure and type of L2 did not differ between the groups, when Mongolian-English bilinguals were compared to Mongolian-Russian bilinguals. In conclusion, becoming bilingual at early stages is beneficial in the development of verbal cognition of children.

2-F -90 Effects of selective attention and language experience on cortical entrainment to continuous speech
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The ability to selectively attend to the speech signal amid competing auditory streams is no small feat. Non-native listeners are particularly challenged when processing speech in the context of competing maskers. One putative mechanism underlying the ability to attend to a specific speech signal is enhanced cortical entrainment to the speech envelope (Golumbic et al., 2013; O'Sullivan et al., 2015). However, the extent to which cortical entrainment to the speech envelope relates to speech comprehension is still under debate (Ding et al., 2014). Here we aimed to better understand the attentional effects on the neural encoding of the speech envelope through a comparison of listener groups that differed in language proficiency for the tested speech stimuli. Across two conditions, continuous English speech and pure tone sequence stimuli were simultaneously presented to native and non-native English listeners while electroencephalography (EEG) responses were recorded. In one condition, participants were instructed to attend to the speech stream (attended speech); in another condition, participants were instructed to attend to the tone sequence (unattended speech). To measure speech comprehension and ensure modulation of attention to speech across conditions, participants answered multiple-choice questions after each trial. In all participants, speech comprehension accuracy and cortical entrainment to the speech envelope was greater in the attended

speech condition relative to the unattended speech condition. Interestingly, while non-native listeners demonstrated better envelope entrainment in the attended speech condition relative to native listeners, native listeners demonstrated better speech comprehension. No group neural differences were found in the unattended condition. Our findings suggest that while attention to the speech stream enhances cortical entrainment to the envelope, this mechanism itself is not sufficient to ensure high speech comprehension.

2-F -91 Electrophysiological markers of auditory temporal processing impairment in word deafness

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The neurobehavioral syndrome of word deafness is characterized by severe difficulties in understanding and reproducing spoken language with otherwise preserved speech production and nonauditory language comprehension. Neuropsychological studies have implicated disturbances of auditory temporal processing as underlying in the impairment of auditory comprehension. Few electrophysiological investigations have helped to specify the precise nature and stage at which auditory processing is compromised. We describe here some novel electrophysiological findings comparing steady-state and traditional transient cortical responses in two cases of word deafness, one with unilateral and one with bilateral temporal lobe damage. The traditional ?oddball? evoked potential (TOEP) paradigm presented a brief complex tone (250 msec) repeatedly at irregular intervals (1.2-2 seconds) and patients responded whenever they heard an infrequently presented ?oddball?complex tone that differed in pitch. In the steady-state auditory evoked potential (SSAEP) paradigm, responses were recorded to a continuous tone frequency modulated (FM) by brief cosine pulses four times a second. The N100 and P200 components of transient cortical responses showed normal latencies and broadly normal amplitudes. By contrast, SSAEPs to 50 ms FM pulses appeared absent in both patients. Responses to 100 ms FM pulses were absent in the patient with bilateral lesions while the patient with unilateral left temporal damage produced identifiable responses that were abnormal in amplitude and latency particularly over the left cerebral hemisphere. These findings reveal that SSAEP's to rapid FM provide are extremely sensitive to the auditory pathophysiology underlying word deafness. The findings support theories that the word deafness is based in gross impairment of auditory mechanisms underlying the analysis of rapid frequency changes in sound.

2-F -92 Transforming continuous temporal cues to a categorical spatial code in human speech cortex

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During speech perception, listeners extract acoustic cues from a continuous sensory signal to map it onto phonetic categories. Many such cues are encoded within the fine temporal structure of speech. For example, voice-onset time (VOT), the interval between a stop consonant's release and the onset of voicing, distinguishes voiced (e.g., /b/, short VOT) from voiceless (e.g., /p/, long VOT) stops in English. The neurophysiological mechanisms that allow listeners to distinguish sounds that differ in temporal cues remain unclear. We recorded neural activity directly from the cortex of 9 human subjects while they listened to and categorized syllables along a VOT continuum from /ba/ (0ms VOT) to /pa/ (50ms VOT). We found that spatially distinct neural populations respond preferentially to one category (either /b/ or /p/). In both populations, responses are sensitive to VOT differences within the preferred, but not the non-preferred, category. This graded VOT encoding rapidly evolves to reflect the behavioral response function, showing that categorical perception of VOT emerges across time in auditory cortex. To probe what computations might give rise to these response properties, we implemented a neural network model that simulates neuronal populations as leaky integrators tuned to detect either coincident or temporally-lagged burst and voicing cues. The same temporal dynamics and encoding patterns observed in real neural data emerged in the model, suggesting that local tuning for distinct spectral cues at precise lags may underlie temporal cue integration in auditory cortex. Finally, neural responses to naturally-produced speech sounds differing in VOT (e.g., /d/ vs. /t/, /g/ vs. /k/) showed that neuronal tuning for this temporal cue generalized across different spectral cues. Our results provide direct evidence that continuous temporal information is transformed into a categorical spatial code by discrete, phonetically-tuned neural populations in human auditory cortex.

2-F -93 O-15 water PET study of speech in noise processing in cochlear implant patients

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One of the most important issues in hearing impairment (HI) is difficulty with speech in noisy real-world environments. Recent research in normal hearing listeners indicates that auditory cortex is active while abstracting speech objects from noise and provides input to fronto-temporal networks for further perceptual, attentional, and semantic analysis. We sought to understand whether the neural mechanisms by which cochlear implant listeners detect speech in noisy environments are similar. We measured cerebral blood flow using [O-15] water positron emission tomography (PET) in 9 cochlear implant patients while they listened to 2-min blocks of continuous sentences in noise or noise alone (matched on RMS sound level). On a given run for speech in noise (7 dB), 30 unique sentence tokens (~2.5 sec length) were presented (1.5 sec inter stimulus interval). We acquired 12 scans (6 each condition, random order) to allow for single subject inference. PET data were analyzed in SPM12 using a flexible factorial model. We found robust activations in single subjects for the contrast speech in noise vs noise in auditory cortex (lateral Heschl's gyrus and planum temporale) and inferior frontal cortex (frontal operculum and inferior frontal gyrus) bilaterally ($p<0.05$, uncorrected). The activity patterns were very similar across subjects and at the group level 5mm radius regions of interest auditory cortex and inferior frontal cortex were significant ($p<0.05$, corrected). Data collection has begun for 10 age-matched normal hearing control subjects for comparison of neural substrate of the network and overall activity level. We expect to find similar brain activations in auditory cortex and IFG. However, differences between the groups may reflect signal audibility and effort. These results support a similar model for speech in noise processing in cochlear implant patients and normal hearing listeners, and identify key brain regions to target for improved cochlear implant performance.

2-F -94 Modulation of human auditory cortical responses by a short disruption of auditory feedback

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Speech motor control requires the timely integration of vocal-motor and sensory information. Particularly, auditory feedback is crucial for online monitoring of speech production. To study the neural networks involved in speech control, we introduced a sudden and short perturbation in the auditory feedback that human subjects received when speaking. Particularly, feedback was shifted in time (delayed) by 180 ms for a variable short period in pseudorandomized trials. Voice was recorded and subsequently played back to the subjects for comparisons between auditory and motor activity. Five surgical epilepsy patients performed the task while we recorded local field potentials from multicontact intracranial electrodes implanted for clinical purposes. Utterances were blindly rated by a trained linguist. All subjects exhibited some degree of speech disruption in trials with delayed auditory feedback. Moreover, significantly more utterances were rated as abnormal in trials in which feedback was disrupted. The abnormalities more frequently identified in these trials were utterance prolongation and a change in speech rate. Consistently across patients, the perturbation in auditory feedback induced modulation of high gamma power (HGP, 70-150 Hz) in the posterior superior temporal gyrus (STG) during vocal production. Other high-order auditory areas (MTG, SCG) also showed an increase in HGP during speech in trials with a disrupted feedback. Moreover, HGP was also modulated in these auditory areas when subjects listened to their vocalizations in the delayed feedback condition. Interestingly, beta power (12-20 Hz) was suppressed in speech trials with a delayed auditory feedback. This effect was predominantly located in temporal pole electrodes and was specific of vocal control. These preliminary results show how a sudden and short delay in auditory feedback affects speech production and reveal the neural mechanisms of speech control in the human brain.

2-F -95 Examining relationships between brain structure in infancy and subsequent language skills in preschool

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A rich body of evidence has identified the neural basis for language that is already evident even before birth, and longitudinal studies have observed that behavioral and neural responses to language-related stimuli in early infancy predict language ability at the preschool age. These neuroimaging studies have predominantly employed electrophysiological methods to characterize brain activity, yet, the brain structure associated with language processing in infancy remains understudied and structural connectivity and its relationship to language has yet to be investigated longitudinally. The present study investigates how brain structure relates to emerging language skills by tracking properties of white matter connectivity and language development from infancy to preschool. This study draws from an ongoing longitudinal investigation of children with and without familial risk for language-based learning difficulties. Initially, structural MRI and DTI were successfully acquired with infants (ages 4-12 months) using a natural sleep technique. Automated Fiber Quantification was employed to estimate white matter properties. Language abilities were also characterized in infancy. Infants were then longitudinally enrolled and completed a follow-up MRI and behavioral assessment in preschool, which included a comprehensive language evaluation. Longitudinal analyses were employed to examine the extent to which properties of language-related white matter tracts in infancy may be predictive of subsequent language skills in preschool while accounting for possible contributing factors, which include age, gender, socioeconomic status, and family history of language and literacy difficulties. Preliminary findings establish significant relationships between structural connectivity in infancy and language outcomes in preschool. This research has the potential to uncover white matter characteristics in infancy that underlie the developmental trajectory of language in early childhood.

2-G -107 Neural representation of temporal fine structure and envelope in human auditory cortex

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In our auditory processing, the peripheral system firstly filters broadband signals into narrowband waves, and then decomposes narrowband waves into quickly-varying temporal fine structures (TFSs) and slowly-varying envelopes. The sustained neural responses in auditory cortex show significant high-fidelity of the speech envelope, which is substantially effected by the regularities of TFS. Although previous neurophysiological studies have revealed the temporal processing mechanisms in various levels of auditory system, how TFS and envelope are processing in auditory cortex is still under debated. In this study, using stereo-electroencephalographic (sEEG) with both highly temporal and spatial resolutions, we obtained electrophysiological data directly from primary auditory cortex (PAC) and non-primary auditory cortices (non-PAC) in intractable epileptic patients with inverse polarity stimulation when patients were listening to narrowband noises with different interaural correlations (IAC: +1, -1). PAC was functionally defined based on the presence of early P20/N30 components. The results showed that the TFS-sensitive responses (difference between IAC = +1 and IAC = -1) were shown in alpha (8-13 Hz) and beta (14-30 Hz) band within PAC and non-PAC areas, but were shown in high-gamma (60-120 Hz) band only within non-PAC areas. Furthermore, envelope entrainment in PAC was significantly reduced by the interaural TFS discrepancy while envelope entrainment in non-PAC was not affected by TFS. In addition, a significant correlation between temporal fine structure and envelope excited alpha band amplitudes was shown in PAC. In conclusion, the TFS and envelope were processed hierarchically and built up gradually in human auditory cortex.

2-G -108 Model-matched sounds reveal that spectrotemporal modulations capture neural tuning in primary but not non-primary auditory cortex

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Many natural sounds have distinctive patterns of amplitude modulation in frequency and time. Speech and music, for instance, feature temporal modulations at syllable and beat rates, respectively, and exhibit spectral modulations from harmonic frequencies. Inspired by these acoustic regularities and by models of primary visual cortex, the auditory cortex has been hypothesized to analyze sounds with filters tuned to such modulations. This standard model is widely used, but its validity for human auditory cortex remains unclear. We tested the model by synthesizing 'model-matched' sounds, each of which was designed to evoke the same response as a natural sound in the model. For each natural sound, we synthesized four model-matched sounds, each of which was constrained by a different model (capturing frequency spectrum only, spectrum temporal modulation, spectrum spectral modulation, spectrum spectrotemporal modulation). Notably, the synthesized sounds were often perceptually distinct from the natural sounds they were matched to, even for sounds matched in both spectral and temporal modulation (presumably because the sounds lacked higher-order statistical structure not captured by such modulations). In primary auditory cortex, we found that fMRI responses to natural and model-matched sounds were nearly equivalent, but only when the model-matched sounds were constrained by both temporal and spectral modulations. This finding suggests that spectrotemporal modulations determine most of the response to natural sounds in primary auditory cortex. By contrast, in non-primary regions, responses to natural and model-matched sounds diverged, even for sounds matched on both spectral and temporal modulation statistics. This finding suggests that spectrotemporal modulations may capture primary auditory cortical tuning, but that non-primary regions represent additional higher-order sound features not well described by current models.

2-G -109 Repetition suppression effect for emotional content

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Emotional sounds are highly salient auditory stimuli whose processing involves interactions between the auditory cortex (AC) and the amygdala (Amy) (Fecteau et al., 2007; Frühholz et al., 2016). Repetition suppression (RS) effect has been observed for non-emotional environmental sounds within the early-stage auditory areas (Da Costa et al., 2015). In this study, we investigate the representation of emotional sounds within early-stage auditory areas, the voice area (VA) (Belin et al., 2000) and Amy, using a RS paradigm. Subjects (N=10) listen to a battery of emotional sounds (Aeschlimann et al., 2008) comprising two categories (human vocalizations and non-vocalizations) and three valences (positive, neutral and negative), resulting in six conditions (each condition was presented six times: twice per block). BOLD time-courses for each region of interest were extracted using Matlab scripts. Classic GLM analysis (BrainVoyager) revealed a strong effect for the contrast 'Sounds vs. Silence' on the supratemporal plane, STG and STS ($q(FDR)<0.05$, $p<0.002$). The contrast 'Human vocalizations vs. Non-vocalizations' highlighted a strong activation in STS, in the region corresponding to VA ($q(FDR)<0.05$, $p<0.0004$). Finally the contrast 'Emotional sounds vs. Neutral sounds' resulted in restricted activations in STG ($q(FDR)<0.05$, $p<0.0001$), and Amy ($p<0.009$, uncorrected). BOLD time-courses revealed a similar processing in both hemispheres within Amy and within AC. VA clearly showed a preference for human vocalizations. This preference was also present, to a lesser extent, in the AC. Amy preferred emotional sounds compared to neutral sounds, while AC and VA showed the reverse. We observed a general effect of RS in each region, with a stronger effect for human vocalizations in VA and emotional sounds in Amy. Overall, our results showed a strong repetition suppression effect for the affective information of vocal and environmental sounds in both auditory areas an

2-G -110 Effects of auditory selective attention on phoneme-level processing in a multi-speaker environment

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Humans have the remarkable ability to selectively focus on a single speaker in a multi-speaker environment. The neural mechanisms that underlie this phenomenon nonetheless remain incompletely understood. In particular, there has been longstanding debate over whether attention to speech operates at an early stage in the speech processing hierarchy based on physical characteristics of the stimulus or later on during higher-order linguistic processing. Progress to resolve this has been hindered by the fact that fMRI lacks temporal resolution, whilst ERP-based EEG studies limit paradigms to the use of discrete stimuli such as isolated syllables and words. Recently, the use of system identification to linearly fit models that map between stimulus features to concurrently recorded EEG has been found to be effective for studying the processing of natural, continuous speech (Lalor & Foxe, 2010) and cocktail party attention in particular (Power et al., 2012). Using this method, EEG has been found to be sensitive to both low-level acoustics as well as higher-level categorical speech features like phonemes (Di Liberto et al., 2015). Here, we employ this approach in a multi-speaker paradigm to identify differences between phoneme-level processing in attended and unattended speech. Participants attended to one of two concurrently presented speakers (perceived to be positioned on their right and left) whilst scalp EEG was recorded. We computed models - known as temporal response functions - that map from the attended and unattended phoneme-level features to EEG. We then assessed these models in terms of their ability to predict novel EEG data during cocktail party attention. Comparison of model performances for attended and unattended speech permit the assessment of how auditory selective attention affects the processing of phonemes, a high-level speech characteristic. These effects are compared to those found when relying on lower-level speech representations like the envelope.

2-H -118 Frequency-specificity of corticofugal postsynaptic potentials in the mouse midbrain

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Corticofugal system implements a highly frequency-specific modulation of the sound information processing in the ascending auditory system. Specifically, focal electrical stimulation of the primary auditory cortex (ESAI, AI) facilitates subcortical neurons when the best frequency (BF) of subcortical neurons is identical to the BF of cortical neurons (physiologically matched). In contrast, ESAI suppresses subcortical neurons when their BFs are different (unmatched). ESAI also shifts the BFs of unmatched subcortical neurons towards the BF of cortical neurons. It is noted that all previous physiological findings are achieved by extracellular recording. To date, little is known about the cellular mechanism(s) underlying the highly frequency-specific corticofugal modulation. An immediate question raised here is if the postsynaptic membrane potential is depolarized or hyperpolarized following ESAI. Since the inactivation of the entire auditory cortex reduces tone-evoked spike number of neurons in the central nucleus of the inferior colliculus (ICc) by 30-50%, our hypothesis is that ESAI should primarily induce excitatory postsynaptic potential (EPSP) in the ICc neurons. In this study, the membrane potential of mouse ICc neurons was recorded by in vivo whole cell patch current-clamp. We found that ESAI induced EPSP of ICc neurons. Further analysis indicated that the ESAI-induced ICc EPSP was related to the BF difference of AI and ICc neurons. The EPSP induced by ESAI was larger in matched ICc neurons than in unmatched ones. The electrical current for inducing minimal EPSPs was smaller in matched ICc neurons than in unmatched one (23.78 ± 10.97 μA vs. 45.20 ± 17.66 μA, $p < 0.01$). Our data suggests that corticocollicular synapses are excitatory. Corticofugal synaptic efficacy relies heavily on the frequency tuning relationship between the stimulated AI and recorded ICc neurons.

2-H -119 Task based modulation of MGB at 7T. A frequentist and Bayesian analysis

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Previous work indicated that task-dependent modulation of the medial geniculate body (MGB) is behaviorally relevant for speech recognition [von Kriegstein et al., 2008]. The MGB is commonly divided into lemniscal and non-lemniscal parts [Bartlett 2013]. To-date it is unclear which part is modulated by a speech task. Here we used 7 T fMRI to test the task dependent modulation of MGB to eventually address this question. Twenty-eight healthy participants (19 female) listened to vowel-consonant-vowel syllables spoken by male or female voices and pressed a button if the syllable changed (speech task). In the control task listeners attended to speaker voice and pressed a button if the speaker changed (speaker task). To independently localize the MGB a sparse sampling, fast event related design was used with natural sound stimuli. This paradigm together with computational modeling has enabled the localization of the tonotopically organized non-lemniscal ventral subdivision of the MGB (MGBv) [Moerel et al. 2015]. Data were analyzed using SPM12 with Frequentist and Bayesian estimation. A significant result was obtained for the left MGB explained by the behavioral percent correct speech score using small volume correction (p=0.035). For the Bayesian inference a log-odds of 2.020 was found in the left MGB for the same contrast, which translates to a probability of responses of 0.883. This research shows that the task based modulation of the MGB, especially with respect to fast varying stimuli can be seen using ultra high field fMRI at 7 T. The results reproduce previous ones found with a lower magnetic field, and strengthen the hypothesis of cortical feedback loops to Thalamic auditory centers involved in speech processing. In a next step we will investigate whether the task-dependent modulation is located in the MGBv.

2-H -120 Experiential- and online-changes in subcortical auditory processing arise through distinct mechanisms

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Auditory enrichment, such as lifelong bilingual experience, enhances subcortical auditory processing. This plasticity is hypothesized to result from top-down signals modulating auditory processing and is believed to have functional consequences for real-world listening. From this enrichment hypothesis, we tested the prediction that experience-dependent enhancements interact with online changes to auditory processing. Specifically, we examined whether bilingual subcortical auditory processing enhancements are called upon when selectively attending to a competing talker, a common occurrence during real-world listening. We recorded auditory-evoked subcortical responses (frequency-following responses) to competing talkers under active (selective-attention task) and passive (movie watching) listening conditions in bilinguals and monolinguals. We found that the groups performed similarly on the active-listening task and both bilinguals and monolinguals showed a decrease in subcortical activity when actively attending to the competing talkers, compared to passive listening. Consistent with previous studies, regardless of listening condition, subcortical auditory processing was larger in the bilinguals. Thus, the experiential increase was in the opposite direction as the online-processing decrease. These results suggest that the two forms of plasticity arise through different mechanisms but that long-term and online changes work concertedly during active listening. From these findings we propose that experience-dependent enhancements facilitate active listening, possibly by extending the dynamic range over which subcortical neurons can be shaped online by attentional mechanisms. This research is funded by NSF BCS-1430400, NIH DC009399, NIH 5F31DC014221, the Mathers Foundations, and the Knowles Hearing Center, Northwestern University.

2-L-124 Neuronal activity packets as basic units of neuronal code

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Neurons are active in a coordinated fashion, for example, an onset response to auditory stimuli usually evokes a 50-100ms long burst of population activity. Recently it has been shown that such 'packets' of neuronal activity are not randomly organized, but rather composed of stereotypical sequential spiking patterns. It has been shown that such packets are ubiquitous feature of stimulus evoked as well as of spontaneous network activity, and are present across different brain states. Although these packets have a generally conserved sequential spiking structure, the exact timing and number of spikes fired by each neuron within a packet can be modified depending on the stimuli. Here we present evidence that packets can be a good candidate for basic building blocks or 'the words' of neuronal coding, and can explain the mechanisms underlying multiple recent observations about neuronal coding, such as: multiplexing, LFP phase coding, and provide a possible connection between memory preplay and replay.

2-I -128 Auditory steady state brain responses as a measure for atypical neural encoding of speech
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Auditory steady state responses (ASSR) detected in the EEG provide a paradigm to investigate aspects of neural temporal processing and encoding of speech beyond the auditory periphery, with emphasis on synchronized neural activity. EEG allows to sample the neural activity from brainstem to cortex and has the perspective of broad clinical application, particularly in special subject populations, such as cochlear implant patients. ASSR to auditory stimuli with speech spectrum carrier waves modulated at rates prominent in the speech envelope, provide building blocks for investigations of neural processing of speech. Different modulation frequencies relate to specific brain oscillations and signal generators from brainstem to cortex for modulations of about 100 Hz down to a few Hz. The measures used are signal-to-noise ratio, amplitude, laterality, connectivity, etc. Appropriate advanced signal processing techniques have been developed to interpret neural activity at source level and to minimize electrical artifacts which is a prerequisite for applications in cochlear implants. Using ASSR our recent research shows that speech-specific temporal information is being processed differently in the typical and atypical developing brain, with examples of the aging human auditory system and the developmental disorder dyslexia, respectively. Lower brainstem responses seem to be compensated by higher activity at the level of the cortex, and particularly at the most prominent modulations in speech. As an example in cochlear implants we have shown that different hemispheric brain activity is generated with electrical compared to acoustical auditory stimulation. Moreover, ASSRs can be used as a beyond-periphery objective measure to characterize and optimize the electrical stimulation channels, and to develop new stimulation strategies.

2-I -129 Acute and long-term circuit level effects of sound trauma in the auditory cortex
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We inflicted acute noise-trauma induced hearing loss (NIHL) in Mongolian gerbils by exposing them bilaterally to a 125 dB SPL, near-field 2 kHz pure tone over 75 minutes. Bilateral laminar LFP signals (to calculate the current-source density; CSD) were recorded at various locations of the tonotopic gradient of auditory cortex at three time points, before, acutely after the trauma, and after 4-7 weeks of recovery. Profound acute threshold increases of cortical activity recovered to significant extents after weeks. To quantify the contributions of lateral, cross-columnar input to the overall cortical synaptic current flow, we analyzed the relative residual of the CSD-based rate-level- and frequency-response-functions. This analysis revealed that the trauma acutely led to reduced overall cortical activity accompanied by a relative increase of lateral cortico-cortical contribution to a given activation pattern. Our data hence suggests an acute relative gain of horizontal cortical activity which might potentially be due to an accompanying lack of lateral inhibition. Over time we found the reversed effect, namely that cortico-cortical contributions normalized to pre-trauma levels, while the overall cortical activity generally increased. These long-term effects after recovery correlated with an overall increase of early granular and infragranular sink activity indicative of increased lemniscal thalamocortical synaptic input. Therefore, our data are compatible with a central gain enhancement of local, afferent inputs in auditory cortex immediately after trauma, which is further reflected by increased translaminar activity spread in supragranular and infragranular layers. After recovery the tonotopy showed a profound lack of BF-regions in the trauma affected range from 2 - 8 kHz. Our findings hence suggest a long-term recalibration of local intra-columnar circuits compensating the deafferented input around the trauma and the potential acute lack of lateral inhibition.

2-I -130 Cortical auditory evoked potential in children at risk of dyslexia

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Dyslexia is a reading disorder related to phonological deficits. The earlier children at risk for literacy problems are identified the better. In this work, we tried to associate at risk for dyslexia in Brazilian Portuguese children with anomalies in Cortical Auditory Evoked Potentials (CAEP). Our sample was composed of 18 children who tested positive for reading difficulties (15 males, 6-14 years old). Subjects had normal hearing threshold and no alteration in tympanometry. Stimuli were phonemic sounds /ba/ and /da/ delivered to each ear individually CAEP componentes P1, N1, P2 and N2 were not found in all individuals and component N2 was found with minor frequency (72,22% for right ear stimulation, 72,22% for /ba/ and 94,44% for /da/). There was no difference in individual ear response to stimulation. However, when comparing response for /da/ anda /ba/ in each ear there was difference in component P1 is latency (p=0,037) and amplitude (p=0,017) for the left and right ear, respectively. Also, N2 amplitude (p=0,056) evoked by the two stimuli was different for the right ear. Thus, despite tha lack fo significance when comparing both ears, there is a difference in processing ears for different verbal stimulus tested, because of the difference between P1 and N2, was not homogeneous. The inhomogeneity between latency and amplitude of the cortical components can be justified by an alteration in the processing of linguistic information. In this manner, results corroborate literature. The achievement of new studies by widening he sample is suggested.

2-I -131 Impact of unilateral Cochlear Implantation in single sided deafness in multi-sound environments

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Locating the spatial origin of a target sound among various distracting sounds (the so-called "cocktail-party situation") represents an enormous challenge for the auditory system in everyday behavior. Healthy individuals compensate by processing interaural time and level differencs (ITD, ILD) and filtering out the range of distracting stimuli. For patients with single sided deafness (SSD) locating a target sound is (virtually) not possible. A unilateral cochlear implant (CI) helps to re-establish a certain degree of binaural hearing. However, influence of cochlear implantation in single sided deafness for sound localization in a complex multi-sound, "cocktail-party" environment is yet unknown. We tested the ability of patients with CI in SSD to localize single target sounds among various, simultaneously presented distractors. To evaluate long-term development, measurements were performed before cochlear implantation and up to 4 years after implantation. We found that unilateral cochlear implantation markedly improved the ability to localize sound sources in a complex multi-sound environment. The most profound change of sound localization ability was observed within 6 months postoperatively. After this time period the improved level of performance stayed relatively constant. We conclude, that cochlear implantation in SSD helps to re-establish patients' ability to localize target sounds in complex multi-sound environments.

2-I -132 Structural imaging of the deafened brain - a review

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The deafened brain has been a challenging target of neuroimaging studies in recent years. With respect to the three magnetic resonance imaging (MRI) modalities, there have been more than 60 functional MRI studies of brain activation but just 24 MRI and 17 diffusion tensor imaging (DTI) structural studies which are reviewed herein. For MRI, there is a wide variation in the sizes and ages of the samples which are by design homogeneous. While morphometry focused on mostly volumes, five studies measured cortical thickness and one measured surface area. Unilateral and/or bilateral differences were observed in structures such as the Heschl's gyrus and planum temporale, motor cortex, frontal cortex including Broca's area, occipital cortex including early visual areas, corpus callosum, insula, fusiform and cerebellum. Asymmetry in temporal lobe structures mostly preserved. For DTI, analyses were mostly confirmatory in that differences in scalar measures were seen in the temporal and occipital regions such as the acoustic radiation, the optic radiation, superior temporal gyrus, corpus callosum and the longitudinal fasisculi. These structural analyses were based on whole brain analyses which involve smoothing and for significance a large sample size is sought. In contrast, a region of interest (ROI) approach maybe more meaningful and sensitive. For cortical structures, volume should be characterized as the product of two independent measures - surface area and thickness (of the gray/white area rather than the pial surface). Given the effect of brain function on cortical thickness and genetics on deafness, it may be best to analyze thickness and surface area separately. There is potential for neuroimaging to uncover biomarkers for monitoring of progress with amplification in people with hearing loss. Changes in brain activity and cognition should be measured with respect to morphometric measures such as thickness, surface area and connectivity in addition to shape analysis.

2-J -142 Predictions for human and animal experiments linking neural adaptation to temporal binding in auditory cortex

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The auditory cortex (AC) creates representations of sound sequences by adjusting its dynamics for processing incoming stimuli according to stimulus history. This process is termed temporal binding. Previous studies have suggested that the underlying mechanism of temporal binding is short-term synaptic depression (STSD) which can be summarized in one central parameter τ, the time constant of recovery from synaptic depression. We performed simulations to investigate how τ might be reflected in classical N1m adaptation phenomena and temporal binding, with a view of exploring whether adaptation could predict temporal binding ability. We used the computational model of May et al. (2015) of AC anatomy and physiology where connections are modulated by STSD. The model describes neural activity in AC on the single column and population level. For simulating adaptation phenomena

we used a repetitive stimulation paradigm where stimuli are presented at regular stimulus-onset intervals (SOIs) and SOI is varied across stimulus blocks. These simulations replicated the dependence of the N1m response on SOI and showed that this is determined by τ. However, for both intra- and extracortical measurements, the simulations suggest that (1) the SOI dependence of peak amplitudes results in an adaptation time constant α which is a poor estimate of τ, and (2) α varies across cortical measurement location even if τ is a spatial constant. For examining temporal binding we used three-tone sequences of a constant duration and where the position of the second tone can vary. The simulations predict that the ability of AC to distinguish between these sequences depends on τ and is tuned to sequence duration. In conclusion, our results predict that the time constant of N1m adaptation indexes temporal binding ability. However, estimating τ itself is a complex problem: its solution probably requires the use of multiple experimental paradigms. Supported by DFG projects He1721/101,2 and SFB/TRR 31

2-J -143 Epigenetic mechanisms modulate the formation of auditory memories in songbirds

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How do naturally salient sounds like conspecific vocal communications have unique access to memory encoding and storage? Neural mechanisms exist to detect, learn, and remember auditory cues. Long term memory (LTM), for example, requires gene expression for long-lasting plasticity in the auditory system to encode relevant acoustics over time. Molecular mechanisms regulate gene expression. We investigated the epigenetic enzyme histone deacetylase 3 (HDAC3) to determine how it could gate an experience with conspecific vocalizations into memory. Bieszczad et al. (2015) showed that rats treated with a HDAC3-selective inhibitor (HDAC3i) acquired a specific memory for the frequency and intensity of a synthetic pure tone associated with reward. We show that HDAC3i enables the transformation of a limited experience with a natural, ethologically-relevant song into LTM for that song, in the adult bird brain. The caudomedial nidopallium (NCM) is an area analogous to superficial layers of mammalian A1 or secondary cortex, known to function in song discrimination and memory. NCM neurons undergo neuroplasticity in the form of stimulus-specific adaptation where evoked responses to familiar sounds adapt more slowly than to novel sounds. Comparison of adaptation rates (slope of decrease in response amplitude as a function of song repetition number) between familiar vs. novel songs provides a measure of the neural strength of memory for familiar songs. Normally, at least 200 repetitions (200X) of one conspecific song is necessary to produce LTM (>20h later). Birds with fewer repetitions (20X) treated with HDAC3i (vs. vehicle) were able to remember a song >20h later. Strikingly, HDAC3i enabled song memory with a lateralized effect: only left NCM exhibited neuronal memories and zenk gene expression in HDAC3i-treated birds compared to right. Therefore, HDAC3i transforms sub-threshold auditory experiences into LTM by reorganizing the neural representations of salient sounds.

2-J -144 Structural correlates of auditory cognition and language in early adolescence

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This work seeks structural correlates of auditory cognition and language in school children of the St. Thomas More School (Newcastle, UK). As part of a whole-year group (n = 238), the participating children (n = 42, age 13-14) had previously undergone detailed behavioural testing. Auditory testing included

tasks of pitch, rhythm, and timbre (modulation) processing at different levels of complexity; language testing comprised of a battery of 6 standard tests of reading and phonological skill, plus non-verbal and verbal standard intelligence tests. Correlations are sought between auditory and language skill (single tasks and principle components (PC)) and brain structure (structural MRI at 3T). The partaking subset of children was representative of the whole year-group in task performance and intellectual ability, and showed the same relationship between auditory and language skill (for instance, Spearman's rho = 0.52, $p < 0.01$ between first principle components) as found in the broader population (Grube et al., 2012, Proc Royal Soc B). Voxel-based morphometry (implemented in SPM 8) was used to seek structural correlates in grey matter (GM) density, whilst partialling out non-verbal IQ. One striking correlation is demonstrated between GM density in the region of the left intra-parietal sulcus (IPS) and auditory PC1 (Pearson $r = 0.47$, $p < 0.05$), as well as with language PC1 (Pearson $r = 0.55$, $p < .01$), and in addition a rhythm measure. Further analyses are being carried out to test in more detail the relationship between specific auditory and language skills and brain structure and the effect of non-verbal IQ. The data so far support a possible structural basis for auditory processing and language skill, and the link between the two. We suggest a mechanism of structural correlation that reflects the yoked development of auditory and language skill, with a particular role for rhythmic sequence processing.

2-K -149 Two-photon imaging reveals "salt and pepper" tonotopy in ferret primary auditory cortex

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Tonotopic organization has been a widely accepted property of the primary auditory cortex for over 50 years. It has been demonstrated in numerous electrophysiological studies across a wide range of mammals, including rodents, cats, ferrets, and primates. Nonetheless, recent studies in mice have challenged our understanding of tonotopy. Studies using 2-photon calcium imaging (2PI) to examine the activity of auditory cortical cells with unprecedented spatial resolution have shown that although tonotopic organization is visible at a large scale, neighboring neurons can have vastly different frequency preferences (Bandyopadhyay et al. 2010; Rothschild et al. 2012; Panniello et al., submitted). As 2PI studies of auditory cortex to date have all been carried out in the mouse, it remains unclear whether this "salt and pepper" tonotopy is a general feature of mammalian auditory cortex, or a peculiarity of mice. To address this controversy, we have carried out 2PI in the auditory cortex of a carnivore - Mustela putorius furo. Each ferret (n=6) was injected with AAV1 expressing a genetically encoded calcium indicator (GCaMP6m) in the primary auditory cortex. Four weeks later, a craniotomy was performed above the injection sites, and we used a Thorlabs B-scope to image neural responses within imaging fields (200 x 200µm; 100 - 400µm deep; corresponding to layers II/III) under medetomidine-ketamine anesthesia. Pure tones (1.2 - 41 kHz; 40 - 100 dB SPL) were presented to derive the Frequency Response Area of individual neurons. Our results show that although the classical tonotopic organization is visible across the cortical surface, neurons within an imaging field can widely vary in their frequency preferences. Quantitative analyses confirm that the local variation in best frequency is similar in mice and ferrets. Therefore, the salt and pepper tonotopy described in the mouse seems to be a common organizational feature of mammalian auditory cortex.

2-L -160 Towards a better understanding of music processing by studying responses in mouse auditory cortex evoked by complex sounds

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Previous studies showed that neural responses in primary auditory cortex (A1) evoked by complex sounds cannot be easily predicted. High non-linearity of auditory responses does not allow to clearly identify a functional role of A1. Here we ask whether neural responses in mouse A1 evoked by different pitch representations, like pure tones (PTs), harmonic tones (HTs) and missing fundamental frequency tones (MFFTs) can be somehow predicted. Firstly, in vivo electrophysiology recordings from A1 were collected while exposing mice to different representations of pitch (PTs, HTs, MFFTs). Stimuli at 60 dB varied from 50 to 500 ms in duration and from 50 to 2000 ms in interstimulus intervals. Our results showed that PTs, HTs and MFFTs evoked similar number of spikes in A1. By varying stimulus duration and intervals we identified the similar pattern of responses in A1 (amplitude, stimulus specific adaptation, onset latency) evoked by different pitch representations. Secondly, by varying stimuli in sound level and frequency we determined tuning receptive fields for pitches represented by PTs, HTs and MFFTs. We confirmed that neurons in mouse A1 are not only specifically tuned to single frequencies represented by pure tones but that similar tuning properties exist also for HTs and MFFTs. Our preliminary results suggest that responses to more complex sounds than pure tones could be possibly predicted in A1. Existence of tuning to HTs and MFFTs with more stable auditory responses in A1 supports the hypothesis that mouse A1 responds to auditory objects and not only to specific sound parameters. Considering this preliminary data, we will further characterize auditory responses to more complex sound features encoded in music, and identify the involvement of crucial neuronal circuits and cortical regions.

2-L -161 Intracortical microstimulation enhances the induced response following post-excitatory inhibition in the primary auditory cortex

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The stereotypical response of the primary auditory cortex to a short transient stimulus consists of a strong primary excitation, a period of post-excitatory inhibition and a secondary, weaker excitation. This secondary, long-latency excitation is the result of complex network processing, involving the primary auditory field and higher order areas. It consists of a combination of evoked and induced response components. In previous work (Voigt et al., 2017; Brain Stim) we have shown, that focused, low-current intracortical microstimulation (ICMS) is able to activate cortical processing in the primary auditory cortex in a layer-specific manner. In the present study we document that ICMS is also able to modulate ongoing processing by enhancing the long-latency secondary excitation. We recorded surface and deep layer-specific neuronal responses from the auditory cortex of guinea pigs (n=9) under ketamine/xylazine anesthesia in response to either transient acoustic (click, 40dB above thr.) or electric (single-pulse, biphasic, ~9µA, 200µs/phase) stimulation, or a combination of both. Time-frequency representations of the population responses were calculated using a wavelet analysis. While both acoustic and electric stimulation evoked the primary, excitatory response component, focused ICMS failed to show long-latency responses. A combination of acoustic and electric stimulation led to non-linear effects on the cortical response pattern. There was a supra-additive enhancement of the secondary, induced excitation. That is, the combined stimulation resulted in a stronger response than the sum of the individual responses. The enhancement of long-latency response components in the primary auditory cortex hints at the involvement of additional neuronal resources in processing of combined acoustic and electric stimuli and the possibility of modulating active cortical processes with focused electrical stimulation. Supported by Deutsche Forschungsgemeinschaft (Exc 1077)

2-L -162 New fMRI evidence supporting an opponent hemifield code representation for space in the auditory cortex of primates

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One fundamental goal of the brain is to predict sensory events in the environment in order to spatially direct actions. In vision, the ability to identify and locate objects depends on two cortical pathways: a ventral "what" stream supporting object recognition and a dorsal "where" stream supporting object localization (Mishkin & Ungerleider, 1982). While this hierarchical model has received strong support in vision, in audition (Rauschecker & Tian, 2000), the "analogues" functional roles have remained rather elusive, particularly for the dorsal "where" stream (Zatorre et al., 2002). For this talk, I will review recent findings based on functional magnetic resonance imaging (fMRI) of macaque auditory cortex (Ortiz-Rios et al., 2017) indicating that acoustic space is represented by a distributed opponent code rather than by a local spatial topography as in vision. I will discuss these results within a cortical framework that is based on cortico-cortical lateral inhibition which might explain the rise in spatial sensitivity along the anterior-posterior axis. These new findings in macaques, taken together with recent human neuroimaging studies (Salminen et al. 2009; Derey et al. 2016) indicates that acoustic space in the auditory cortex of primates is coded by the same coding principles available in other mammalian species auditory structures (Grothe et al., 2010).

2-L -163 Persistent activity in auditory cortex during passive listening

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Persistent activity, the elevated firing of a neuron after the termination of a stimulus, is hypothesized to play a critical role in working memory. This form of activity is therefore typically studied within the context of a behavioural task, which includes a working memory component. Here we investigated whether persistent activity is observed in primary sensory cortex and thalamus in the absence of any explicit behavioural task. We recorded spiking activity from single units in the auditory cortex (fields A1, R and RT) and thalamus of awake, passively-listening marmosets. We observed persistent activity that lasted for hundreds of milliseconds following the termination of the acoustic stimulus, in the absence of a task. Shorter duration persistent activity was observed following both phasic onset responses and sustained responses during the stimulus. Longer duration persistent activity, on the order of seconds, was observed following dramatic suppression in firing during the stimulus. These response types were observed across all cortical fields tested, as well as in thalamus. Thalamic persistent activity was of shorter duration than the responses observed in cortex, indicating that cortical persistent activity is not simply inherited from thalamus. These responses were observed for all stimulus categories tested and following all types of evoked response (adapting, sustained, ramping or suppressed), indicating that persistent activity in a subset of neurons may be a basic feature of sensory responses in the auditory cortex. Given that these responses were observed in passively listening animals, persistent activity in sensory cortex may have functional importance beyond storing behaviourally relevant information in working memory.

2-L -164 Optimal features for auditory recognition

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A central challenge in auditory neuroscience is to understand how observed patterns of neural activity in the auditory system relate to behavior. For example, neurons in primary (A1) as well as higher auditory cortical areas exhibit highly nonlinear and surprisingly specific tuning properties, but our understanding of these responses is only at a descriptive level, and the critical question of how these responses might support behavior remains unresolved. Here, we show that nonlinear A1 responses encode essential features for the classification of ethologically-relevant sounds such as conspecific vocalizations (calls). In vocal animals, increasing neural resources are committed for the processing of calls as one ascends the auditory processing hierarchy. Therefore, the categorization of call types is a reasonable computational goal for the auditory cortex in these animals. We asked, using a theoretical information-maximization approach, how this goal can be best accomplished. Based on an earlier model for visual classification, we first randomly generated a large number of mid-level features from marmoset calls, and used a greedy-search algorithm to choose the most informative and least redundant feature set for call categorization. We found that call categorization could be accomplished with high accuracy using just a small number of features. Most interestingly, the responses of model feature-selective neurons predicted nonlinear neural responses in marmoset A1 in astonishing detail. We further found that when using artificial call stimuli which were parametrically varied along multiple dimensions from a 'mean' vocalization, the performance of the model mirrored marmoset behavior. These results demonstrate that the auditory cortex uses a mid-level feature based strategy for the recognition of complex sounds. These results further suggest that the tuning properties of neurons in higher auditory cortical stages are likely the result of goal-directed optimization.

2-L -165 Modulation of neuronal activity by acoustic context in rodent auditory cortex

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Hearing critically relies on two complementary functions. A listener must identify, or characterize a sound, as well as determine its relative temporal position to other sounds, i.e. its acoustic context. Though the physical laws governing sound transmission embeds acoustic signals with an inherent chronology, damage to the auditory cortex, but not lower auditory centers, impairs temporal processing of sequential sounds. Neurons in the auditory cortex, but not the auditory thalamus, modulate their response to a sound based on recent acoustic history, suggesting the cortex is necessary for temporal processing of sequential sounds because it represents a sound's acoustic context. However, the influence of acoustic history has only been shown via different combinations of preceding sounds. If the auditory cortex indeed represents acoustic context, this representation should change in response to different configurations of preceding sound as well different combinations. To test this, we simultaneously recorded single-unit activity at multiple sites (>15) in the auditory cortex of anesthetized rats in response to sequences comprised of distinct configurations of the same four pure tones (ABCD). To isolate the effect of configuration, we compared activity in response to the terminal tone in the sequence (ABCD) across different configurations with the same terminal tone (e.g. ABCD vs CBAD). We observed that neurons in the auditory cortex indeed modulated their response to the terminal tone based on the configuration of preceding tones. This finding supports the hypothesis that cortical neurons represent not only the content of sound, but its acoustic context as well. Further analysis will identify critical sequential features underlying the representation of acoustic context in auditory cortex.

2-L -166 Network receptive field modelling reveals extensive integration and multi-feature selectivity in auditory cortical neurons

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Sensory neurons are commonly characterized using the receptive field, which describes the stimulus characteristics upon which their response linearly depends. Although this approach has a long and distinguished history, the simplicity of the receptive field leads to substantial limitations in the complexity of neural processing it can capture. In reality, the response of a neuron is a consequence of the network of neurons to which it is connected, where each neuron is a nonlinear unit. Here, we reveal some of this complexity by describing neural responses to natural sounds using a nonlinear feedforward network model (a network receptive field). We show that primary auditory cortical neurons integrate in a complex non-linear manner over a substantially larger spectrotemporal domain than is seen in their receptive fields derived using standard approaches. The network receptive field, a parsimonious network whose output is found to integrate over up to 7 nonlinear units, each with its own spectrotemporal receptive field, consistently better predicts neural responses to natural sounds than conventional receptive field models. Notably, network receptive fields reveal many nonlinear aspects of auditory processing hidden from standard analyses. They reveal separate excitatory and inhibitory units with different non-linear properties, and the interaction of the units captures important operations such as gain control and conjunctive feature selectivity. The conjunctive effects, where neurons respond only if several particular features are present together, enable increased selectivity for specific complex spectrotemporal structures, and may constitute an important stage in the sound recognition. In conclusion, we demonstrate that fitting auditory cortical neural responses with network models gives substantially improved predictive power and reveals key non-linear aspects of cortical processing.

2-L -167 Decoding the cortical representation of auditory motion using EEG

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It is of increasing practical interest to be able to decode the spatial characteristics of an auditory scene from electrophysiological signals. This has potential applications in cognitively controlled hearing aids and for the evaluation of virtual acoustic environments. However, the cortical representation of auditory space is not well characterized - particularly as it relates to auditory motion - and the possibility of decoding cortical signals using non-invasive neuroimaging techniques remains unclear. In previous work (Bednar et al 2017) we showed that we can classify evoked electroencephalographic (EEG) responses to discrete static sound stimuli as a function of their location in space. In the present study, we extend this work with the aim of decoding the trajectory of continuous, moving auditory stimuli. Subjects listened to white noise over headphones, which had been spectro-temporally modified to be perceived as randomly moving on a semi-circular trajectory in the horizontal plane. Participants were asked to respond to infrequent tremolo targets which were embedded in the stimuli. While subjects listened to the stimuli, we recorded their EEG using a 128-channel acquisition system. The data were analyzed by 1) deriving a linear mapping, known as a temporal response function (TRF), between the stimulus and a training set of EEG data, and 2) using the TRF to reconstruct an estimate of the time-varying sound

source azimuth from a test set of EEG data. Preliminary results show that we can decode sound trajectory with a reconstruction accuracy significantly above chance level. We find that reconstruction accuracy is highest when the sound trajectory is estimated using alpha-filtered EEG (8-12hz). Moreover, the subsequent analysis of the reconstruction model parameters reveals strong alpha-power lateralization at the occipital regions of the scalp.

Poster Session 3 | Thursday, September 14, 3:30 PM – 6:00 PM

3-A -6 Pairing vagus nerve stimulation with speech sounds alters multiple auditory fields

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Pairing a specific sound with neuromodulator release results in an expansion of the primary auditory cortex (A1) region that responds to the paired sound. For example, pairing a 9 kHz tone with vagus nerve stimulation (VNS) expands the A1 region that responds to 9 kHz. Similarly, pairing speech sounds with VNS expands the A1 region responding to the paired speech sounds and increases the response strength evoked by the paired speech sounds. It is currently unknown whether VNS sound pairing alters other auditory fields. Previous literature involving auditory operant training suggests that different auditory fields exhibit distinct changes following training. We hypothesize that pairing VNS with speech sounds will alter neural responses in each auditory field, with differences in the plasticity across fields. In this study, we paired VNS with speech sounds 300 times per day for 20 days, and then recorded neural responses in 5 auditory fields: the inferior colliculus, primary auditory cortex, anterior auditory field, ventral auditory field, and posterior auditory field. One group of rats experienced VNS paired with the presentation of 'rad' and 'lad', a second group experienced VNS paired with the presentation of 'rad' but not the background sound 'lad', and a third group served as experimentally naïve control animals. Preliminary results indicate that VNS speech pairing alters responses in each of the recorded fields, although each field responds distinctly. Insights derived from this study may influence the development of new behavioral and sensory techniques to treat the communication impairments in disorders such as autism that result in part from a degraded representation of speech sounds.

3-A -7 Musical effects on oscillatory markers of sustained attention

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For decades, neuroscientists have tried to map brain oscillations to their cognitive correlates. Evidence from animal models has shown that neuronal oscillations can entrain to external stimuli in precise frequencies, thereby altering the brain state. The auditory neuroscience startup company, Brain.fm, purports to use music as an external stimulus to enhance attention, by entraining the brain?s activity to rhythmic amplitude modulations. Here, we hypothesize that listening to Brain.fm music would affect the oscillatory activity of the attention networks in the brain. We recorded EEG from human subjects (N =

50) who completed the Sustained Attention to Response Task, which measures sustained attention via reaction time variability, while listening to Brain.fm as compared to three control conditions: silence, pink noise, and Spotify music. Behavioral results showed that reaction time variability, an index of mind-wandering, decreases over time during Brain.fm but increases in all other conditions, indicating that Brain.fm helps sustain attention over time. EEG data show that compared to the all control conditions, Brain.fm elicits lower activity in the alpha (8-12 Hz) range, coupled with localized increases in left frontal regions in the gamma (26-32 Hz) range. Results show that external stimulation, delivered via algorithmically generated music, can affect sustained attention by entraining oscillatory activity in the brain. The increases in high-frequency power are localized to left frontal regions and may reflect activity in attention networks, sustained by entrainment to Brain.fm. Mind-wandering, or the lapse of sustained attention, hurts productivity and is associated with lower well-being. By changing neuronal oscillations that enable sustained attention, Brain.fm can reduce mind-wandering, thus boosting productivity and increasing focus.

3-B -15 Optogenetic stimulation of the VTA: self-.stimulation behavior and impact on cortical processing in primary auditory cortex of Mongolian gerbils

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Recent studies revealed that the systemic application of SKF 38393, a D1/D5 agonist, is influencing the cortical processing within the primary auditory cortex (AI) in a layer-dependent manner. Also, systemic and local application of SKF 38393 (Schicknick et al. 2008) improved the salient detection of behaviorally relevant stimuli during an auditory task, confirming the role of dopamine (DA) as learning-related reward signal yielding performance improvement. Yet, the network mechanism of DA, released in AI by projections from the ventral tegmental area (VTA), influencing cortical processing is still elusive. In this study, we established optogenetically controlled dopamine release of VTA neurons in Mongolian gerbils confirmed by successful self-stimulation behavior. We then recorded laminar local field potentials (LFP) in AI before, during and after optogenetically controlled dopamine release of VTA neurons in the anesthetized Mongolian gerbil. Using current source density (CSD) analysis, we found an overall increase of cortical activation, particularly due to increased infra- and supragranular activity after stimulation with non-best frequencies. Our findings are in accordance with the hypothesis of increased infragranular thalamo-cortical inputs (bottom-up) and a subsequent increase of supragranular activity indicative for augmented corticocortical activity spread across cortical columns. Thereby, dopamine might promote the integration of behaviorally relevant inputs in associative networks within AI (top-down).

3-B -16 Influence of earlier exposure to sound on the development of cortical auditory evoked potentials in premature infants during the first three months

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The development of auditory pathways is heavily influenced by auditory experience. Preterm infants are exposed prematurely to external sounds and the effects of this environmental influence on auditory development are unknown. Objective: to evaluate the consequences of earlier exposure to unattenuated external sounds on the development of central auditory pathways of preterm infants. Methods: We evaluated the latency of the cortical auditory evoked potential's P1 component of 24 preterm infants at 1 and 3 months of age. The participants were divided into four groups, according to corrected gestational age: one old month preterm infants G1, G2 term babies evaluated at one month of corrected gestational age, G3 premature babies and G4 term babies evaluated at evaluated at 3 months of corrected gestational age. Results: Latency of P1 decreased from 1 to 3 months of age in both term and preterm infants. However, the decrease was steepest for preterm infants. Conclusion: The differential profile of P1 latency variation in preterm and term infants suggest an acceleration of the development of auditive cortical pathways in the first group, probably due to the early exposure of ambient sounds

3-B -17 Role of thalamocortical interactions in stimulus discrimination and detection

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Corticothalamic feedback can shape the receptive field properties of thalamic neurons and modulate the temporal precision of their responses. We studied the role of corticothalamic feedback in the ability of ferrets to detect a mistuned harmonic in a complex tone. Using chromophore-targeted laser photolysis, we evaluated the behavioral effects of selective elimination of corticothalamic neurons, projecting from the primary auditory cortex (A1) to the ventral division of the medial geniculate body (MGBv). Bilateral injections of the light-sensitive chromophore chlorin e6 were made in MGBv with subsequent infrared laser illumination of A1 to induce apoptosis of retrogradely-labeled neurons in layer VI. Mistuning detection performance was tested using a go/no-go behavioral task before and after laser illumination of A1. Prior to elimination of corticothalamic neurons, ferrets had mistuning detection thresholds of <1 Hz. Neurons in the MGBv responded to harmonic complex tones, and exhibited an increase in firing rate and temporal pattern changes when one frequency component in the complex tone was mistuned. Animals with corticothalamic lesions were impaired their mistuning detection ability, as indicated by decreased d' values, a shift of the psychometric curves towards higher mistuning values, and increased thresholds. These results support a role for A1-MGBv feedback in the accurate recognition of complex auditory stimuli. More recently, we studied the thalamocortical transformation of receptive fields following critical-period exposure of rats to noise of different statistics. Their ability to detect vocalizations presented in noise with different statistics was measured to further explore foreground/background segregation mechanisms. Recordings from thalamic and cortical neurons showed differences between normal and exposed animals in the cortical receptive fields. Potential relationships between behavior and thalamocortical receptive fields will be discussed.

3-B -18 Mutual information in the auditory thalamocortical circuit diminishes with loss of consciousness

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In addition to its scientific importance, understanding the mechanisms of loss of consciousness is crucial to the development of intraoperative tools to assess global neural state. We provide empirical support for the information integration theory of consciousness, which attempts to characterize unconsciousness as a state of reduced or uncorrelated information transmission. Four male Sprague-Dawley rats were each implanted with two Neuronexus 16-channel electrode arrays, targeting the medial geniculate body (MGB) and the primary auditory cortex (A1). After recovery, electrical stimulation at 4 different levels, ranging from subthreshold to well above threshold behaviorally, occurred on one of their electrodes while neural responses were recorded on the other. Thalamocortical stimulation consisted of a mock thalamic burst triplet of pulses at 300 Hz in MGB. Corticothalamic stimulation consisted of a singular pulse delivered to deeper layers of A1 (layers 5-6). In addition, responses to simple sounds were recorded, including frequency tuning, rate-level, and click train responses. Neural responses were filtered into both local field potentials and multiunit activity (sorted offline with waveclus2). Near-loss of consciousness was induced via IV administration of sub-hypnotic and just-hypnotic doses of isoflurane (approximately 0.6% or 0.9%) and low doses of the sedative dexmedetomidine (i.v. 0.016 or 0.024 mg/kg/hour). Data were collected in the wakeful state before and after sub- or just-hypnotic levels of unconsciousness were induced. Mutual information was assessed over 200 ms or in 20x10 ms bins after stimulus offset. Preliminary results show a reduction in effective information using both measurement schemes for both agents and not stimulation amplitude dependent. These results suggest that mutual information can be a sensitive measure of brain state, such that clinical measures of mutual information may be useful as an index of consciousness.

3-C-24 Natural aging diminishes multisensory connections of primary sensory cortices

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During aging, the senses deprive "naturally", e.g., many hearing and tactile receptors vanish, retinal functions decrease, and reaction times to simple sensory stimuli increase. Older humans show also longer reaction times to multisensory (e.g., audiovisual) stimuli but a greater multisensory enhancement than younger people (Laurienti et al., 2006). We have previously argued that short-latency multisensory integration processes might substantially be mediated by crossmodel thalamocortical (TC) and corticocortical (CC) connection of low-level sensory cortices like the primary auditory (A1), somatosensory (S1), and visual (V1) cortex (Henschke et al., 2015). Here, we investigated qualitative and quantitative changes of these connections due to aging. We injected a retrograde tracer into A1, S1, and V1 of Mongolian gerbils around postnatal day 120 (young adult) and P1000 (very old). Further, we investigated possible cellular mechanisms for the observed changes in multisensory connectivity using antibodies against Caspase-3 (apoptosis marker) and GAP43 (marker for axonal reorganization). Our findings demonstrate that in young adult animals, several auditory, somatosensory, and visual thalamic nuclei project not only to the primary sensory area of their respective sensory modality but also to areas of other sensory modalities. Further, we found direct CC connections among the primary sensory cortices themselves. In very old animals, multisensory TC and CC connections decreased dramatically or vanished entirely. At the mechanistic level, we could show that during aging, TC and CC projection neurons do not die; instead major axonal reorganization processes take place, which are mediated by neurons within the non-lemniscal thalamic nuclei and primary sensory cortices themselves. We conclude that the partial loss and restructuring of multisensory connections during aging can explain the above mentioned changes in multisensory performance of older individuals.

3-C-25 Role of perceptual reasoning in reading skill

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Introduction Auditory perception has unique direct impact upon reading development rather oral language ability. Different aspects studied are discrimination, phonological judgment, working memory, short-term memory, reading errors and comparison with visuo-spatial perception Methods Sample dyslexics (n=20) age-matched typical readers (n=20) Assessments clinical performance (auditory discrimination, digit-span, familiar-lexical pair recall, visual discrimination, phonological judgment, reading errors) Functional magnetic resonance imaging (fMRI) phonological judgment task acquired in 3T MR scanner (M/s. Philips) 32 channel head coil using EPI & data processed in SPM12 Task was presented with E-Prime & ESys System Clinical data analyzed using SPSS Results & Discussion Mean scores of two groups on auditory discrimination was statistically significant (t 1.861 p 0.047) & frequency of errors showed variability in dyslexics. Phonological judgment was statistically different (t 1.631, p 0.108) in dyslexic children and BOLD activity of right hemispheric precuneus, cuneus and parahippocampal gyrus with cingulate suggesting visuo-spatial attention and visual-constructive processing. Speech perception might have been also constrained by auditory memory as dyslexics working memory performance showed variability and short-term memory was significantly different in two groups (t 3.024; p 0.004). Visual discrimination performance was observed not significantly different (t -1.173, p 0.245). Reading errors at single alphabet or number was not significantly different but significantly different at string level (t -8.052, p< 0.0001) (equal to/more than 3 symbols). Visual symbolic skill (discrimination, recognition) & speech perception (phonological awareness/discrimination) indicated that dyslexic children have modified top-down feedback associated with differences in visuo-spatial attentional control and inhibition of distractors rather than only auditory perception deficits.

3-D -63 Frequency-specific attentional modulation in human primary auditory cortex and midbrain

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Human brain studies have shown that paying auditory attention to a specific audio frequency selectively enhances activity in primary auditory cortex (PAC) at the tonotopic site (frequency channel) that represents the attended frequency, relative to channels representing unattended frequencies. Animal findings indicate that neurons in PAC achieve this ?attentional spotlight? by adapting their frequency tuning, yet comparable evidence in humans is scarce. It is further unknown whether this spotlight also operates at lower-order sound processing stages in the human midbrain. To address these issues, we assessed the spectral tuning of frequency channels in human PAC and inferior colliculus (IC), using 7-Tesla functional magnetic resonance imaging (FMRI) for frequency mapping while listeners paid selective attention to target auditory streams with specific frequencies. We found that shifts in frequency-specific attention alter the response gain, but not tuning profile, of frequency channels in PAC. The observed gain modulation was strongest in channels tuned to low frequencies (0.4-1.0kHz) and varied near-monotonically across channels, giving rise to a tonotopic modulation pattern resembling the attentional spotlight. We observed weaker significant spatial patterns of attentional modulation in human IC. Our FMRI results indicate that the frequency-specific attentional spotlight arises primarily from tonotopic gain modulation, rather than adapted frequency tuning, in neuronal populations of human PAC. Moreover, endogenous frequency-specific attention modulates afferent sound processing also in human IC, although the spotlight seems to diminish toward this lower-order processing stage. Our study sheds light on how the human auditory pathway adapts to the different demands of selective hearing.

3-D -64 Selective attention modulates the cortical segregation of irrelevant sounds in natural listening situations

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In everyday life, we routinely process mixtures of natural sounds. In a restaurant, we can listen to the voice of a friend, chatter from other tables or the tunes of music. This requires the auditory system to segregate the auditory signal into separate sources (i.e., streams) and select the relevant one. However, it is still debated how stream selection and stream segregation interact: are streams formed pre-attentively or does selective attention influence the formation of streams? Here, we tested whether and to what extent the human auditory system forms auditory streams irrelevant to the listeners' current goal in a natural, cocktail party-like situation. Using auditory scenes consisting of two speakers and music (1-min duration) and EEG-based measures of neural sound tracking, we identified participants' (N=17) cortical representations of the three individual streams. We assessed the separation of representations and utilized selective listening tasks to test whether the separation of task-irrelevant sounds depended on selective attention. Our results showed that irrelevant streams are cortically represented as mixtures rather than separate sources, consistent with the notion that selective attention contributes functionally to stream formation in cortex. Interestingly, the strength of this neural mixing of the irrelevant streams depended on their acoustical similarity, suggesting additional contributions from sensory-driven stream segregation processes which render acoustically distinct streams readily available for selection. In sum, our results indicate that the representation of simultaneous natural sounds outside the focus of attention reflects their mixture rather than separate sounds, especially if the irrelevant sources are acoustically similar. Focusing selective attention on a specific sound source in a natural listening situation facilitates the formation and segregation of its representation in cortex.

3-D -65 Effect of spectral resolution on neural entrainment of the speech envelope

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Objectives: Research shows that neural entrainment of the speech envelope correlates with speech intelligibility. While the speech envelope is known to be the primary cue of speech intelligibility, other features still have an effect on speech reception. While keeping the envelope fixed we investigated the effect of spectral resolution on neural entrainment, thus varying speech intelligibility. Methods: Nine normal-hearing subjects listened to vocoded running speech in quiet and stationary noise (3 dB SNR) while their EEG was recorded. Using vocoded speech, we were able to preserve temporal envelope cues while degrading the spectral resolution. By measuring behavioural speech understanding during the EEG experiment we known the words understood by the subject. We trained a linear multi-channel decoder to reconstruct the speech envelope from the EEG signal, and by correlating it with the original envelope, we estimated the neural entrainment of the stimulus. Results: We found that vocoded speech in noise elicited different neural entrainment in different oscillation bands compared to vocoded speech in quiet. We also found an increase in neural entrainment when more vocoder bands were used, indicating that spectral resolution can have measurable effects on speech envelope based methods. These results correlate with behaviourally measured speech intelligibility. Conclusion: Since neural entrainment appears to be differently affected by noise regarding which oscillation band is considered, we can hypothesise the existence of a neural mechanism related to the suppression of the added stationary noise. Furthermore, even though the neural entrainment measure only depends on the speech envelope, we can still see an effect of spectral resolution, indicating that it is not merely a measure of peripheral coding of the envelope, but also relates to speech intelligibility.

3-D -66 Early cochlear stimulation can restore auditory cortical glucose metabolism in short term period

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For the deaf patients, cochlear implant was most promising rehabilitation method up to now. However, the results of cochlear implant showed variability among the patients. One of the important determinant was the duration of deafness. During the period of deafness, cortical neuronal plasticity was happened and it affects the result of rehabilitation. So early detection and rehabilitation are major concerns in these days. The aim of this study was to show the effect of early implantation to the brain in the postlingually deafened animal model. Eight adult cats were included in the study. All cats showed normal hearing level. They were divided to two groups: control and implanted. All cats were deafened using co-administration of kanamycin and ethacrynic acid. Hearing levels were tested at 4 weeks later and confirmed profound hearing loss. The implanted group (n=4) received cochlear implantation using Nucleus 422 devices to their right ears. The control group (n=4) was left without any rehabilitation. Brain images using glucose positron emission tomography (PET) were acquired three times; normal hearing state, 4 months after deafening procedure and 11 months after deafening procedure. The implanted group received cochlear stimulation from 5 months after deafening procedure. Cochlear stimulation was performed for 6 months, 8 hours per day. We compared the change of glucose metabolism between two groups. The glucose metabolism of the auditory cortex was decreased at four-month after deafening procedure as our previous report (paired t-test, $P<0.01$). There were no differences between the control and implanted groups. After cochlear stimulation, the glucose metabolism of auditory cortical areas was normalized. Hearing loss affects auditory cortical activity and cochlear stimulation increased auditory cortical activity in short term period. Early cochlear stimulation was beneficial in the aspect of cortical metabolism.

3-D -67 Modulation of the cortical frequency-following response (FFR) via transcranial magnetic stimulation

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Phase-locked firing of neural populations within the auditory system in response to repeating sound waves produces a brain response known as the frequency following response (FFR). The FFR contains information about how well a listener represents periodicity in sound, which affects downstream auditory processing and is linked to a variety of impairments and training-related enhancements. Using magnetoencephalography (MEG), which allows for better source reconstruction than EEG, we recently identified an unexpected contribution to the FFR from the auditory cortex at a low fundamental frequency (98Hz). Signal strength in the right auditory cortex correlated with measures of musical experience, pitch discrimination thresholds, and speech-in-noise perception accuracy. However, the presence of a cortical FFR contribution has not been established via experimental manipulation. Furthermore, the contribution of the auditory cortex to the more commonly reported EEG FFR has not been measured, nor has its presumed decay at higher frequencies been explored. In the present study, we aim to address these issues by simultaneously recording full-cap EEG data and MEG data while subjects listen to trains of three tones with fundamental frequencies of 98Hz, 131Hz, and 146Hz. Each of 3 recording sessions is preceded by one of 3 transcranial magnetic stimulation (TMS) protocols applied to the right auditory cortex; a sham stimulation control condition, and two stimulation patterns that have been previously shown to produce inhibitory and excitatory responses in the auditory cortex. We report 1) the nature and extent of FFR modulation across TMS conditions, 2) the effect of cortical FFR inhibition on the scalp-recorded EEG signal, and 3) the effect of TMS on cortical FFR as a function of stimulus frequency. The results refine our understanding of the auditory cortex's role in representing pitch-related information and its importance in the interpretation of a large body of existing work.

3-D -68 Reorganization of cortical microcircuits following perceptual auditory learning

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Perceptual learning is a cognitive phenomenon whereby perceptual capabilities improve with training. The neural substrate of perceptual learning is not well understood but probably involves multiple brain regions, one of which is the neocortex. Here, our goal was to describe how learned information is encoded at the functional level of individual cortical neurons and local subnetworks. We focused on the primary auditory cortex (A1), targeting inhibitory and excitatory subpopulations of neurons. First, to study perceptual learning in mice, we developed an automated assay in a learning chamber that we named "the Educage". The Educage is designed to train groups of mice on a two-tone 'go no-go' discrimination task. Once the procedure is learned, task difficulty is gradually increased by decreasing the frequency difference between the two tones. Using this procedure, we have shown that mice became experts in this task and reached their perceptual limits within a few thousands of trials. Second, to study the physiological correlates of learning in A1, we used in vivo two photon targeted patch clamp (TPTP) to measure basic response properties of inhibitory (Parvalbumin positive, PV+) and putative excitatory neurons (PV-) of layer 2/3. We compared the evoked response to pure tones from neurons in A1 of expert and naïve mice. This comparison reveled an increased representation of the trained stimuli, following the learning, by both PV+ and PV− neurons. Using TPTP we also mapped the functional microarchitecture of L2/3, showing increased functional homogeneity for both cell types, and higher temporal correlation in PV+ neurons. Based on these results, we are currently testing a mechanistic scenario for plasticity. Namely, that reorganization of functional connectivity allows excitatory neurons to escape from inhibition and encode behaviorally significant stimuli more reliably.

3-D -69 Dynamic conversion of sensory evidence to decision signal in ferret frontal cortex

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The frontal cortex is often associated with enhancement of relevant information for goal-directed behavior. In particular, frontal cortex (FC) neurons of the behaving ferret have been shown to respond selectively to target auditory stimuli during discrimination tasks (Fritz et al., 2010). However, in natural and cluttered environments, sounds are not necessarily presented in token-based sequences. Instead relevant events are embedded in continuous sound streams and their detection demands to dynamically update the representation of incoming stimuli (Lawlor et al., 2017). Here, we attempt at characterizing the extraction of relevant sensory information from complex continuous sounds performed at the level of frontal areas. To address this question, we trained ferrets on a change detection paradigm where animals have to constantly monitor a stochastic and continuous acoustic stream to detect subtle statistical changes. We then gathered electrophysiological data in the dorso-lateral FC of the behaving ferret. Because modulations in FC neurons' firing rate can be correlated with a large variety of overlapping task-relevant and irrelevant events, we used a Linear Non-Linear Poisson model to disentangle the contribution of different predictors (sound onset, change in stimulus statistics, decision, motor activity...) to those modulations. Our model allows us to orthogonalize the responses to each predictor and quantify their specific contribution to the firing rate of individual neuron. Comparing the neurons' responses for different types of changes and outcomes, we found that neurons encoded both stimulus changes in a stimulus-dependent manner and perceptual decisions in a categorical stimulus-independent fashion. A substantial fraction of the neurons (~25%) displayed a dual encoding of these two types of events, suggesting that conversion from sensory evidence towards a decision signal may take place in the FC.

3-D -70 Cortical mechanisms of perceptual learning in juveniles

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From riding a bike to learning a language, children are considered to be better skill learners than adults. One possible explanation for this superiority is that sensory systems display heightened plasticity during development, and thus may be more responsive to training. Developmental studies have documented differences between juvenile and adult learning, and have identified critical periods during which neural properties are particularly sensitive to environmental experience. However, the neural plasticity that accompanies juvenile learning remains unexplored. To address this issue, we recorded telemetrically from left auditory cortex (ACx) of juvenile gerbils as they trained and improved on an amplitude modulation detection task. Neurometric and psychometric sensitivity were simultaneously tracked across days. As performance improved, juvenile ACx units displayed significant within-animal correlations between neural and behavioral thresholds. These data will be compared to similar recordings from mature adult animals to evaluate whether or not plasticity mechanisms differ.

3-D -71 Genetic access to active neurons in the mouse auditory cortex

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Cortical circuits are often functionally heterogeneous and their responses can be sparse. In the auditory system, it is difficult to access specific local circuits encoding stimuli such as natural sounds as these shape neuronal responses in complex ways; for example, due to their rich frequency content, temporal structure and contextual effects. Here, we used a new method, called TRAP (Targeted Recombination in Active Populations) to identify and access functionally active circuits in the mouse auditory cortex (A1), in vivo. TRAP is based on a Fos-CreERT2 driver line allowing genetic access of temporarily active neurons. We developed and tested a new reporter mouse strain (called TB), which allows the expression of a fluorescent protein and tTA after the excision of a loxP-flanked transcriptional stop signal. The new reporter enables labeling of neurons as well as induction of other genes when these are expressed under the TRE promoter. We calibrated the FosCreERT2xTB system to A1. We demonstrate near zero non-specific labeling in A1 and show up to 3-fold increase in the number of trapped neurons following sound exposure to natural sounds (but not pure tones). Efficient recombination is also shown in other regions of the auditory pathway. In vivo two-photon targeted patch recording from L2/3 neurons shows that TRAPed neurons respond significantly stronger to the trapping stimulus as compared to non-TRAPed neighbors or as compared to control TRAPed neurons. Next, we used this system to investigate plasticity of postpartum mothers. Pup ultrasonic vocalizations (USV) induced higher numbers of recombined neurons in mothers' A1 compared with naïve virgins. USV-TRAPed neurons in mothers were found to have a unique spiking signature suggesting that a newly recruited subpopulation of cortical neurons contribute to efficient encoding of USV. Our method will now be used as a substrate to elucidate the unique neural signature of parental plasticity across the auditory system.

3-D -72 Neural substrate of sound object segregation

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Previous studies reported a double dissociation between deficits in explicit sound localization and in sound object segregation on the basis of spatial cues, suggesting the existence of a position-linked representation of sound objects that is distinct from the position-independent representation within the ventral auditory stream and from the explicit sound localization processing within the dorsal stream. Here we provide evidence for the anatomical substrate of spatial-cue based sound object segregation. Fifty-seven participants (17 controls; 20 patients with left and 20 with right hemispheric damage) were assessed for explicit sound localization and for the effect of spatial release from masking (SRM). The latter used two simultaneous environmental sounds; the position of the masker varied (a central and 2 positions within each hemispace, simulated with interaural time differences) whereas the target remained central. Voxel-based Lesion-Symptom Mapping (VLSM) was applied to either task. Performance in the explicit localization task depended critically on the right parietal cortex, confirming the role of the right dorsal auditory pathway in explicit localization. For the SRM task, separate VLSM analysis was performed for each of the 5 masker positions. It highlighted the critical role of a large temporo-parieto-frontal region within the left hemisphere, independently of the position of the masker. In addition, a smaller parieto-temporal region was highlighted, more specifically when the masker was central or to the right. Thus, explicit sound localization and implicit use of spatial cues for sound object segregation depend on at least partially distinct neural networks. The involvement of a left temporo-parieto-frontal network in the SRM effect is in agreement with the role of a left temporo-frontal network in position-linked representation of sound objects, which was reported in a previous EEG study.

3-D -73 Contributions of glottal-pulse rate and vocal-tract length to perceptual grouping in the cocktail party

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Cocktail parties pose a difficult, but solvable, problem for the auditory system. The cocktail-party problem is made considerably easier when all sounds within the target stream are spoken by the same talker. The so-called "voice-continuity benefit" occurs because speech sounds from a single talker are all similar in terms of certain acoustic features. This makes it easier to group together these sounds as a perceptual object than speech sounds from different talkers. Here, we present two experiments that investigated the relative contributions of two of the most salient voice features to the voice-continuity benefit: glottal-pulse rate (GPR) and vocal-tract length (VTL). In Experiment 1, listeners heard three competing digit sequences presented at different loudspeaker positions. Listeners were asked to report the digit sequence presented at a target position. The experiment employed four conditions differing in terms of (dis-)continuity in GPR and VTL in the target sequence. The results showed that the listeners benefited to a greater extent from continuity in VTL than continuity in GPR. In Experiment 2, we tested whether perceptual grouping can be based on a single voice feature when the target object is spatially dynamic. Experiment 2 was identical to Experiment 1, except that the target position varied randomly from digit to digit. The results of Experiment 2 showed that listeners only benefited from continuity in both GPR and VTL, but not from continuity in a single voice feature. Taken together, our findings suggest that the cocktail-party problem is easier to solve when all the sounds in the target stream can be grouped together based on VTL than GPR. In the context of spatial uncertainty, however, perceptual grouping seems to rely on continuity in more than one voice feature.

3-D -74 Functional neuroimaging of binaural sensitivity in human auditory cortex

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Compared to single-unit recordings, functional magnetic resonance imaging [fMRI] offers the advantage of sampling activity simultaneously in all regions of the cerebral cortex across a wide range of stimuli and behavioral contexts. Although fMRI data cannot isolate the activity of individual neural elements, such activity can be compared to population activity in neural recordings of targeted regions. A major impediment to such comparisons is that few fMRI studies aim to characterize cortical responses parametrically, i.e. by systematically measuring response functions across a stimulus dimension as is done in neurophysiological recordings. This presentation reviews a series of investigations characterizing binaural sensitivity in human auditory cortex using fMRI. The results reveal strong contralateral preference for interaural-level differences [ILD], and dramatically weaker-but still significant-tuning to interaural-time differences [ITD]. The difference is perplexing because psychophysical ITD cues appear to dominate human spatial hearing. Across several studies, we have used block-wise and event-related fMRI combined with cortical surface mapping, region-based response metrics, and voxel-pattern classification to address several hypotheses regarding the difference between ITD and ILD: (1) spectral and temporal stimulus characteristics that support different potencies of ITD and ILD cues; (2) task-dependent changes in binaural tuning; (3) sharpening of ITD sensitivity when competing sounds are presented; (4) tuning to congruent versus conflicting ITD and ILD cues; and (5) fine-scale cortical topography of ITD preference in individual listeners. Through repeated replication, the combined results provide a clear picture of binaural sensitivity as seen through the lens of fMRI and pave the way to future studies on the cortical processing of auditory space from the single-neuron level to whole-brain cortical networks. [Supported by NIH R01-DC011548]

3-D -75 Selective auditory attention to a single sound stream suppresses responses to temporally non-coherent sounds in ferret auditory cortex

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Human listeners can focus attention on speech of a single speaker in a noisy auditory scene. This ability requires segregating the relevant sound stream and ignoring irrelevant sound sources. Our previous studies proposed that temporal coherence plays an important role in segregating sounds. When ferrets were trained to globally attend to two tone-sequences without any behavioral requirement to differentiate or segregate them, we found that coherent activation of cortical neurons tuned to the two tones (when the sequences were synchronous) induced excitatory interactions (or binding) between them; by contrast, asynchronous tones induced incoherent activation and suppressive interactions the two different frequency channels. The current studies tested the effects of selective attention when ferrets were trained to focus attention on one of the sequences while ignoring the other sounds. We hypothesized that the attended channel would bind all channels that are coherent with it, while suppressing actively those incoherent with it. Two ferrets were trained to listen attentively to detect a small intensity change in a sequence of narrow bandpass noise bursts. This foreground target stream occurred against a background of sequences of two alternating tones: one tone sequence was synchronized with the target noise sounds, while the other tone sequence was out of phase with the target stream (temporally alternated with the target sequence). Using standard neurophysiological techniques, we recorded auditory responses of single units (N=84) in the primary auditory cortex (A1) of behaving animals. Responses from A1 neurons tuned to the tone streams that alternated with targets were significantly suppressed, while responses from neurons tuned to tones that were synchronized with the targets remain intact, providing further support for the temporal coherence hypothesis as the neural mechanism underlying the ability to filter out irrelevant sounds in complex auditory scenes.

3-D -76 Neural decoding of word identity and acoustic prototypicality during speech perception in listeners with and without aphasia

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Aphasia, often a result of left-hemisphere stroke, is characterized by deficits in speech production and perception, both of which rely on robust phonemic representations. The degree to which phonemic representations are spared is often measured in tasks such as speech-sound identification or discrimination and picture-word auditory comprehension. Because persons with aphasia (PWA) may have deficits at various levels of perception and comprehension, and may vary in their ability to perform such tasks, it is desirable to have an objective measure of the quality of their phonemic representations. In this study, we explored the utility of neural decoding accuracy during passive listening as such a measure. Ten PWA and 10 age-matched controls participated in a magnetoencephalography (MEG) study in which they spoke the words 'eat', 'Ed', and 'add' 200 times each, and, in alternating blocks, listened to playback of their own utterances. Within participant, we used vowel acoustics to mark the prototypicality of each utterance. We measured whole-brain MEG sensor data time-locked to vowel onset in each playback trial. We trained a machine learning classifier (Meyers, 2013) to distinguish both coarse (word identity) and fine-grained (acoustic prototypicality) phonemic information in the MEG signal and tested it on held-out portions of the data. Preliminary results indicate that both word identity and acoustic prototypicality can be read out from the neural data of PWA and controls passively listening to their own speech. The former suggests that coarse representations of vowel identity are stable and available for use in speech perception. The latter has implications for speech production: as neural differentiation of prototypicality relates to behavior that decreases acoustic variability (Niziolek et al., 2013), we hypothesize that the accuracy of fine-grained acoustic decoding may relate to an individual's trial-to-trial speech variability and on-line corrective abilities.

3-D -77 Neural source dynamics of brain responses to continuous speech: from acoustics to comprehension

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Reverse correlation of electroencephalography (EEG) and magnetoencephalography (MEG) data is used to analyze neural processing of continuous speech, but such analysis is typically restricted to sensor space. We show that reverse correlation can be applied to distributed minimum norm neural source estimates of MEG data to predict the neural response to continuous speech in time by anatomical location. This procedure allows us to track new aspect of dynamic speech processing by differentiating them anatomically. This is demonstrated with brain responses of young adults listening to segments of an audiobook. Results show that the low level M50 response to speech separates into an earlier (~35 ms) response in auditory cortex, and a later (~50 ms) more dorsal response, consistent with the mouth area of somatosensory cortex, suggesting fast mapping of acoustic information to somatosensory/motor representations. Other responses include the attention-related M100 response to speech, predominantly in right auditory cortex, and a response associated with word-frequency in left auditory cortex, suggesting differential processing of acoustic and lexical information in the two hemispheres. Responses reflecting the different information content of phonemes are found in auditory cortex with differing degrees of lateralization. Finally, a response associated with semantic composition is seen in higher level language areas, anterior temporal lobe and inferior frontal gyrus, demonstrating that even comprehension-related responses can be localized. Our results indicate that MEG responses to continuous speech are rich in dynamic information that can be spatially reconstructed. These novel techniques for studying the neural basis of speech perception with continuous stimuli are especially relevant for speech comprehension, where event-related designs may heavily compromise the naturalness of the stimuli.

3-D -78 Corticostriatal learning systems in auditory categorization

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Some auditory category structures are easily learnable using rules (e.g., auscultation). In contrast, other category structures (e.g., speech) require implicit, pre-decisional integration of multiple dimensions. Single-learning systems approaches posit that a single attention-dependent mechanism is involved that allows learners to extract categories by attending to dimensions that are relevant and ignoring irrelevant dimensions. In contrast, multiple-learning systems approaches argue for feedback-dependent, partially-dissociable, corticostriatal learning systems that allow learners to represent and acquire different category structures. To distinguish single versus multiple learning systems in the auditory domain, we constructed two category structures using ripple sounds. The structures were optimally learnable either by using rules (rule-based; RB), or by implicit pre-decisional integration of spectral and temporal modulations (information-integration; II). Young adults (n = 48) learned to categorize ripples in either RB or II condition using corrective feedback across 240 trials during magnetic resonance imaging. Behaviorally, RB and II category structures were learned to similar extent. Successful categorization was associated with increased activation within the prefrontal cortex (PFC) and the caudate in the RB condition, but only in the motor cortex for the II condition. During feedback processing, successful categorization increased activation within the ventral striatum in both conditions and exclusively within the PFC and caudate in the RB condition. Multivariate pattern analysis revealed the emergence of stimulus categories in the superior temporal gyrus (STG), insular cortex, and the hippocampus in RB, and in the STG, parietal, and motor cortices in the II condition. Our results provide support for multiple

auditory corticostriatal loops that are involved in the representation and acquisition of different types of novel auditory categories.

3-D -79 Perceptual and motor skills

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Numerical Cognition Kids in modern world should receive the most effective education they deserve. They are capable to perceive information faster, with cross-modal processing,activating all senses at once : visual perception, audio analyzers , neuromotor functions. The research Project " Reflection " gives us the explanation in this direction and raises the topic about of the necessity of applying of Digital Key in Primary Music Education. https://www.linkedin.com/pulse/digital-key-initial-music-education-stepanov-sergey?trk=prof-post 3330. 3330. 3512. 3000. 4444. 4333. 3223. 2050. 3330. 3330. 3512. 3000. 4444. 4333. 5542. 1000. NeuromusicGroup Reflection Ukraine

3-D -80 Prenatal noise stress impairs HPA axis and cognitive performance in mice

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Introduction: Noise stress is a common environmental pollutant whose adverse effect on offspring performance has been less studied. We used "noise" as a prenatal stress compared with physical stress to explore the effect of stress during gestation on HPA axis activation, cognitive performance, and motor coordination, as well as in investigating the effect of behavioral assessments on the corticosterone levels. Methods: Three groups of C57BL/6 mice with a gestational history of either noise stress (NS), physical stress (PS), or no stress were examined in behavioral tests including novel object recognition, elevated plus maze, balance beam test, and the Morris water task in adulthood. Plasma corticosterone level was collected one day before starting and one day after finishing the behavioral tests. Results: The corticosterone level was significantly higher before starting the behavioral tests in the NS group than both the PS and control groups. It was significantly increased after the behavioral tests in both prenatal stressed groups relative to the controls. Prenatal stress caused anxiety-like behavior and reduced learning and memory performance in both stressed groups, as well as decreased motor coordination in the NS group relative to the control group. Conclusion: The findings suggested that prenatal NS severely impairs the HPA axis. The results also implied that both prenatal stresses particularly NS negatively impair the offspring's cognitive and motor performance. Both prenatal stressed groups also indicated a strong susceptibility to environmental experiences as stressful conditions.

3-E -82 Identifying perceptually informative acoustic cues in mouse social communication

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Adult male mice produce complex courtship-related communication signals that are thought to be used by females for mate selection. However the acoustic features that are socially informative to the listener (e.g. for judging male fitness), and might be preferentially encoded by auditory neurons, remain unknown. To address this, we first recorded a collection of "courtship songs" produced by male C57B/6 mice in response to urine from conspecific females. These songs are sequences of ultrasonic calls emitted at a rate of 10 calls/second, lasting 35ms on average, with peak frequencies between 67 and 87 kHz. These calls also display amplitude- and frequency-modulation, typically spanning a frequency range of 40 kHz. The aim of this work is to identify the acoustic features of mouse song that are perceptually relevant to the listener during social interactions. To achieve this, we reproduce an ethologically-relevant communicative situation in the laboratory, during which female mice respond to vocalizing males, or playbacks of male song, with an approach behaviour. Here, we quantify female mice's approach to each of two sound sources simultaneously playing back original and acoustically manipulated songs. We are currently testing the impact on the females' behaviour of different spectrotemporal manipulations of the original songs, including phase-scrambling, up- and downward frequency shift, temporal reversal, and disruption of the rhythmic structure of the song. Differences in the time a female spends close to the source of original vs manipulated songs are interpreted as reflective of her perceptual sensitivity to changes in the tested acoustic dimension. By probing the perceptual representation of natural acoustic sequences in mice, this work will help pinpoint the acoustic features extracted during natural communication in a mammalian species, and provide the basis for the future study of the neuronal-level encoding of socially relevant sound patterns.

3-F -96 Contextual effects on the neural encoding of speech sounds

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Our rich and constantly changing auditory environment requires a flexible and dynamic auditory processing system. At the single cell level it has been shown that animal auditory receptive fields are responsive to contextual demands. It is unknown however, how these findings translate to humans and importantly how they translate to naturalistic contexts. We conducted a 7 Tesla fMRI study in which participants listened to speech sounds while performing two different tasks, one linguistic and one paralinguistic, on the very same stimuli. With the use of computational modeling, we mimicked the filtering of sounds by the cochlea as well as acoustic sound decomposition within the auditory cortex. This allowed us to model task-specific voxels' response profiles along different acoustic dimensions, i.e. frequency, spectral modulations and temporal modulations. We found that performance of the two tasks evoked differential neural encoding of the very same sounds in different auditory areas. In early auditory areas (Heschl's gyrus, planum temporale and planum polare) we found tuning for higher frequencies (from 750 Hz to 2kHz) and higher spectral modulations (up to 4 cycles/octave) during the paralinguistic task. Similar tuning was also found in voice-specific areas. In contrast, in later auditory areas (anterior, middle and posterior superior temporal gyrus) we found tuning to lower frequencies (from 400 to 500 Hz) and to faster temporal modulations (up to 50 Hz) during the linguistic task. Successful task performance required participants to focus on distinctive acoustical features of the sound, we therefore further aim to find relationships between the changes in the voxels' response profiles and the acoustics relevant for the task at hand.

3-F -97 Cortical responses in human superior temporal gyrus that differentiate intonation contours in speech are a response to pitch, not fundamental frequency

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Speech intonation is an important component of prosody in all spoken languages. It conveys sentence-level linguistic meaning, such as sentence type (statement vs. question) or focus (which word was emphasized). In our previous work using electrocorticography (ECoG), we showed that specific neural populations in the human superior temporal gyrus (STG) respond differentially to speech stimuli with distinct intonation contours, realized through digital manipulation of the fundamental frequency (f0). Because those stimuli were synthesized to control for intensity and duration of syllables, the only acoustic difference across intonation conditions was f0 over time. Although the f0 of a sound generally determines its perceived pitch, sounds with acoustic energy at the fundamental removed, called 'missing fundamental' stimuli, can also produce a pitch percept. To determine whether STG responses that differentiated intonation contours in speech are a response to pitch or to f0, we created a set of non-speech stimuli that preserved each intonational pitch contour but did not contain f0 and played them to participants while we recorded cortical activity using ECoG. To test whether neural responses to pitch contours in the missing f0 stimuli were similar to neural responses to f0 contours in speech, we used linear discriminant analysis to fit a model predicting the intonation contour from neural responses to speech. We then tested this model on the missing f0 data to see whether the model could discriminate between responses to the missing f0 stimuli. We found that in almost all electrodes (47/49 electrodes from 3 participants), neural activity patterns to the different intonation contours were the same between speech and missing f0 stimuli. This result indicates that the cortical activity in neural populations that differentiate intonation contours in speech can be explained as a response to the perceptual attribute of 'pitch', rather than energy at the fundamental frequency.

3-F -98 Brain signatures of vocal emotional perception

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The human voice is plausibly the most important sound category in a social landscape. In particular, the ability to produce and comprehend emotional cues conveyed through the voice is a cornerstone of effective functioning in a social environment. Despite the increased number of studies probing vocal emotional processing, its neurofunctional correlates remain elusive. We combined event-related potential (ERP) and time-frequency EEG analyses to probe how emotional salience is detected at both preattentive and attentive levels of voice processing. Neutral, happy (laughs) and angry (growls) vocalizations were presented in oddball tasks to 22 participants. In Experiment 1, participants were asked to watch a silent movie and to ignore the vocal sounds. In Experiment 2, participants were asked to silently count the number of low-probability (deviant) vocalizations. The Mismatch Negativity (MMN), Repetition Positivity (Experiment 1) and P3 (P3a/P3b; Experiment 2) ERP components were analyzed, as well as Beta and Alpha induced power. The ERP results demonstrated a modulatory role of stimulus valence. In Experiment 1, the amplitude of the MMN and Repetition Positivity was increased for happy vocalizations, indicating enhanced sensory prediction for laughter. Induced pre-stimulus beta power was increased for happy vocalizations, and predicted the standard positivity modulation. In Experiment 2, the P3b was selectively enhanced for happy voices. The P3b modulation was predicted by pre-stimulus frontal alpha desynchronization. Our findings confirmed that the brain is tuned to detect vocal changes, and that emotional information cannot be ignored even when it is not task-relevant. Increased anticipation and attention to positive vocal cues may reflect their high social significance.

3-F -99 Neural responses to behaviorally relevant syllable sequences in the ferret auditory- and frontal cortices

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Phoneme sequences lie at the core of speech. As a result, spoken language relies not only on the ability to segregate and recognize individual phonemic elements in speech, but also in understanding that ordered combinations of such elements form distinct auditory objects. The generation of these auditory objects, known as words, is essential for language since once we create a sound-to-meaning association, speech relies on recalling these "word memories" when a complex sound input is processed. Such memories may be stored in association cortices and retrieved when a sound input matches a stored acoustic memory template. To explore the neural mechanisms by which the auditory system encodes human speech sounds, we trained ferrets to discriminate tri-syllabic consonant-vowel nonsense words. Ferrets are an excellent animal model to study speech representation because their hearing is similar to humans, their auditory cortex is complex enough to encode all phoneme classes and they can be trained to differentiate and recognize syllable sequences. Several ferrets were trained on a conditioned avoidance GO/NO-GO task to lick a spout for water upon presentation of distractor words (e.g. ABX) but to refrain from licking the spout after a target word (e.g. ABC) was presented. Once animals learned the task, we conducted neurophysiological recordings in primary auditory cortex (A1), secondary auditory cortical areas (dPEG) and frontal cortex (FC) during passive listening and active behavior. Preliminary neurophysiological data indicate that, unlike the stimulus-dependent responses in A1, responses in dPEG reveal differences between target and distractor words based on behavioral context. This study suggests that neurons in dPEG can encode specific syllable sequences. These results will help us understand the neural basis for the representation of complex sound sequences, and yield deeper insight into neural mechanisms underlying initial stages in human speech processing.

3-F -100 Corticostriatal circuitry associated with speech representational plasticity in the superior temporal gyrus

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We examined the neuroplasticity underlying the feedback-dependent acquisition of novel speech categories in the mature adult brain. Our central premise is that the striatum, a brain structure that is sensitive to feedback reward signals during training, mediates the emergence of category representations along the superior temporal gyri (STG). To test this hypothesis, we trained 30 native English speakers to categorize Mandarin lexical tones using trial-by-trial corrective feedback during magnetic resonance images (MRI) scanning. We probed the relationship between corticostriatal circuitry and speech category learning using functional and structural neuroimaging methods. Functional neuroimaging data showed that the putamen, a subregion of the striatum, was activated during corrective feedback. Neural representation of tone categories emerged following training in the bilateral STG, and that individual variability in the neural representation of speech categories was associated with behavioral categorization patterns. We observed increased functional connectivity between the putamen and STG during error-monitoring. Using diffusion tensor imaging, we found that individual differences in the robustness of white-matter connectivity between the STG and the putamen predicted both behavioral learning outcome and the emergence of neural representation in the STG. These results altogether suggest that the formation of speech category representation in the STG is closely linked with the striatal processing of feedback signals during learning. We posit that the corticostriatal circuitry provides neural infrastructure for the emergence of the neural representation of non-native speech categories.

3-F -101 Clarify the upper limit of the speech rate for reading systems

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Text to speech systems are becoming more widely adopted. Various benefits can be achieved by listening to text information from a wide variety of sources. If the optimum speech processing speed limits of the brain can be found, readers can be created to provide a possible faster information transfer rate. To clarify the upper limit of the speech rate for reading systems, data is collected from the neuromagnetic signals emitted from various areas of the brain while changing the speech rate of synthetic speech. The speech synthesis engine was used to synthesize the statement, and the time stretch method was used to generate eight different speech rates as stimuli. MEG recording: Each subject laid on her/his back on a bed in a magnetically shielded room, and listened to the speech stimuli which were presented randomly. Subjects were instructed to press one of two keys (Yes / No) depending on whether they could or could not understand the speech stimuli. We used 400 channels SQUID gradiometer, PQ1400RM made by Yokogawa Electric Corporation. We found a clear correlation between the auditory evoked magnetic fields (AEF) from the left superior temporal gyrus and each syllable structure when the subjects could understand the speech. The AEF component of all syllables was estimated to lie in the left superior temporal gyrus auditory cortex. If the subjects did not understand the speech because it was too fast, the AEF showed no such correlation. It is suggested that each syllable should have the average duration of more than 80 ms to ensure speech understanding. In clarifying the upper limit of the speech rate for reading systems, we find that the upper limit of the speech rate is about 80 ms syllable duration.

3-G -111 Dendritic spine properties distribute differently across different subregions of cat auditory cortex

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The dendritic spine is the principal site for excitatory synapses on cortical neurons and differences in synaptic number and weighting are thought to underlie different processing effects between cortical areas. However, little is known about the synaptic/dendritic spine properties of auditory cortical areas outside of primary auditory cortex (A1). Using Golgi-Cox stained tissue from core auditory areas A1 and anterior auditory field (AAF), and from higher-order auditory Field of the Anterior Ectosylvian Sulcus (FAES) in cats, light microscopic techniques were used to measure and compare dendritic spine density and spine head diameter in each of those regions. The density of dendritic spines was observed to be highest in the higher-order FAES and varied therein by cell-type and cortical layer. In general, spine density was greater for pyramidal than for spiny non-pyramidal neurons, and was lowest within the granular layer (when present) of each region. Similarly, dendritic spine head diameter showed higher mean values for FAES neurons than their core auditory counterparts, and also differed by cortical layer. These observations are important for construction of connectional models of cortical processing directed toward understanding how auditory signals are transformed within different auditory cortical regions.

3-G -112 Modern views on the anatomy of planum temporale

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The planum temporale (PT) is a cortical workhorse for auditory processing. It reveals the most pronounced hemispheric asymmetry out of all structures in the human brain. This anatomical asymmetry has been related to the left-hemisphere dominance of language function. Concealed within the Sylvian fissure, PT is bounded anteriorly by Heschl's gyrus (HG), and posteriorly by the posterior ascending ramus (PAR) of the Sylvian fissure. However, these two anatomical boundaries demonstrate considerable morphological variability. PARs vary in length and angle, and sometimes are absent. In addition, HG often demonstrates a partial or complete duplication. Although previous literature attempting to quantify the structure of PT has considered some of these complexities, new research suggests that the anatomy of PT should be reinvestigated. Therefore, we examined PT using ultra-high-resolution MRIs of 28 healthy adults. The superior temporal plane was exposed via the traditional knife-cut method and PT measurements were taken on each hemisphere's cortical surface. Presence of PAR was determined based on previously established anatomical criteria from our laboratory. HG variations were classified according to the three traditionally-recognized anatomical variants. Inferential statistics were used to determine the effect of PAR presence and HG variant on PT surface area. We found that PT area was significantly larger in hemispheres without PAR compared to hemispheres with PAR. Furthermore, PT area was significantly larger in hemispheres with a single HG compared to hemispheres exhibiting duplications of HG. Our results confirm that the surface area of PT depends on the morphology of neighboring perisylvian structures which contribute to its anatomical asymmetry. This type of translational research has profound implications on how we interpret the effects of cortical lesions, topographic evoked potential mapping and how we draw structure-function correlations between MRI and fMRI.

3-G -113 The representation of spatial location and temporal modulation in marmoset parabelt auditory cortex

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The current working model of primate auditory cortex comprises the hierarchical arrangement of a series of functionally distinct information processing stages: a primary 'core' region, a secondary 'belt' region, and a tertiary 'parabelt' region. The 'auditory dual stream hypothesis' suggests that caudal belt and parabelt regions form a 'where' pathway that selectively processes auditory location, whereas the rostral cortical fields form a 'what' pathway responsible for auditory identification. (Rauschecker 1997, Kaas & Hackett 2000, Romanski et al. 1999) Crucially, data testing this hypothesis have come only from studies in core and belt auditory cortex, and not parabelt. We analyzed single unit receptive field data from extracellular physiology studies in rostral and caudal parabelt in the the awake, behaving marmoset. Unexpectedly, single units throughout parabelt, in both rostral and caudal regions, exhibited sharp tuning for spatial location similar to that found in earlier levels. Neurons in both fields also represented stimulus frequency and temporal modulation with sharp tuning and high fidelity. Thus both identity and location are represented faithfully in both auditory cortical pathways.

3-G -114 Keeping track of sound objects in space

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The dual-stream model stipulates that sound localization takes part in the dorsal (Where) stream. However, Bourquin et al. (2013) proposed a new model with a third stream where position-linked representations of sound objects are distinct from the sound meaning (What) and explicit sound localization (Where). Here we investigated how early auditory areas integrate sound object meaning and binaural cues (interaural time difference) using a repetition suppression (RS) fMRI paradigm at 7T. Similar to Da Costa et al. (2015), subjects listen passively to environmental sounds presented in 30s-blocks of eight repetitions of the same sound object (same category) or eight different sounds objects (different categories). These sounds were either in the center, left or right hemispace (no change within block) or shifted left-to-right or right-to-left after 8s (change within block). Time-courses were analysed with a GLM fit and then extract with BrainVoyager QX. BOLD responses plots and statistical analysis were made using MATLAB scripts. GLM contrast Sound > Silence revealed activations in bilateral STG, right MTG and right IFG ($q(FDR)<0.05$, $p<0.01$). An ANOVA 2 (Category) X 2 (Change) X 2 (Hemisphere) on the BOLD responses showed a main effect of Category in primary auditory cortex (PAC) and planum temporale, main effect of Change in PAC, main effect of Hemisphere in posterior lateral Heschl's gyrus (latHG), interaction Category X Hemisphere in PAC, interaction Category X Change in latHG, interaction Category X Change X Hemisphere in latHG. BOLD responses for each condition showed a greater response for contralateral hemispace and a clear RS effect for both Category and Change in latHG. Overall, our results showed repetition suppression for Category and Change in a region posterior to lateral HG in agreement with the model of a position-linked representation of sound objects at the early stage level.

3-G -115 Sonification of auditory models via synthesis of statistically matched stimuli

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A central goal of auditory neuroscience is to develop models of neural responses and perceptual judgments. Models are often evaluated by measuring their output to a set of sounds and correlating this predicted response with a measured neural response, or by using the model output to predict perceptual judgments. An alternative approach is to synthesize sounds that produce particular values in a model's representation, typically those evoked by a given natural sound. The logic behind model-based sound synthesis is that sounds producing the same response in a model should evoke the same neural response (or percept) if the model replicates the representations underlying the neural response in question (or perception). We implemented a general-purpose optimization method to synthesize sounds from auditory models. The method extends previous sound texture synthesis methods that generate sounds matched on particular statistics (McDermott and Simoncelli, 2011). Unlike previous methods, we utilize automated gradient-based deep learning optimization tools, such that the same synthesis procedure can be applied to any differentiable model. The optimization procedure is implemented in TensorFlow, with a front end that extracts Hilbert envelopes from a cochlear filter bank applied to a sound waveform. Optimization occurs directly on the waveform, eliminating artifacts that could otherwise be created by imposing statistics on a spectrogram-like representation which must be inverted. We used the method to explore synthesis from moments of the waveform, cochlear filter outputs, and modulation filter outputs, as well as correlations between pairs of cochlear or modulation filters. We also compared standard spectrotemporal modulation filters with learned filters from a task-optimized convolutional neural network. The approach facilitates stimulus generation for experiments featuring higher-order statistics, and allows sonification of features in auditory models.

3-H -121 Activating distinct neuronal cell types in auditory cortex differentially affects collicular responses to sounds

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Within the auditory cortex, excitatory and inhibitory dynamics determine frequency selectivity and frequency-modulated (FM) sweep tuning in excitatory cells (Hamilton et al., 2013, Aizenberg et al., 2015; Seybold et al., 2015; Natan et al., 2015; Phillips et al., 2016). Auditory cortex sends an extensive descending pathway to the inferior colliculus, but the function of this pathway remains unclear. Previous studies demonstrated that responses of neurons in the inferior colliculus are altered by focal electrical stimulation and pharmacological inactivation of auditory cortex (Jen et al., 1998; Yan et al., 2005; Zhang et al., 2005). However, these methods lack the ability to manipulate specific cell-types. In this study we combine optogenetic techniques with in vivo electrophysiology to modulate activity of excitatory cells, parvalbumin-positive (PV) interneurons, and somatostatin-positive (SOM) interneurons in the auditory cortex to test whether and how this pathway modulates frequency selectivity and FM sweep tuning in the inferior colliculus. We found that activation of cortical excitatory cells decreased frequency selectivity, while activation of PV interneurons and SOM interneurons increased frequency selectivity in putative excitatory cells in the auditory cortex. However, whereas activation of excitatory cells decreased frequency selectivity and tone-evoked responses in the inferior colliculus, activation of PV interneurons had weak effects on FM sweep direction selectivity and activation of SOM interneurons had weak effects only on spontaneous and tone-evoked responses. These findings suggest that modulation of frequency selectivity in auditory cortex by inhibitory neurons does not necessarily propagate to the inferior colliculus and that PV and SOM interneurons may differentially affect activity in the inferior colliculus.

3-H -122 Measuring effects of attention and predictability on bidirectional interactions between cortex and subcortex during auditory processing

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The auditory pathway contains bidirectional neural connections between cortical and subcortical regions, but how they influence auditory processing is unclear. We are measuring EEG to simultaneously record oscillatory responses indexing cortical and subcortical auditory activity. Specifically, using a 40-Hz amplitude-modulated carrier tone (647 Hz), we are examining the 40 Hz envelope following response (EFR), generated primarily in primary auditory cortex, and the frequency following response (FFR), thought to originate primarily in inferior colliculus. Tones are presented to the right ear in an oddball sequence in which the carrier frequency of the tone is changed to 717 Hz on 20% of repetitions. Participants either attend to the tones by counting the number of deviant tones or listen passively to the tones while watching a silent movie. Predictability of tones is also be manipulated by presenting deviant tones either in a pseudorandom order with the constraint that every deviant tone is followed by at least two standard tones or at a fixed rate occurring every fifth tone. Using symbolic transfer entropy (a recent directional time series analysis that measures the influence from one signal to another) we will determine how the FFR influences the 40 Hz EFR, and vice versa during varying states of attention and predictability of the tones. We predict greater information flow from auditory cortex to sub-cortex during attentive listening and fixed presentation of tones compared to passive listening and random presentation of tones. This technique can elucidate our understanding of top-down and bottom-up processing of sounds. Furthermore, development of this technique will enable analysis of information flow while listening to complex sounds such as speech or music as well as changes in the top-down and bottom-up processing of sounds during development.

3-I -133 Quantifying and comparing connectivity within auditory cortex and between sensory cortices in hearing and deaf cats

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When one sensory modality is lost, compensatory advantages are observed in the remaining senses. There is evidence to suggest these advantages reflect recruitment of cortical areas that normally process sound. In the cat, crossmodal reorganization of auditory cortex appears to be field specific. While little or no activity is evoked in primary cortical regions by visual and somatosensory stimulation, higher-level fields confer increased peripheral acuity and improved visual motion detection. In order to better understand the changes in neural connections that underscore these functional adaptations, we have undertaken a series of detailed anatomical studies aimed at quantifying and comparing the patterns of connectivity in hearing and deaf animals. A retrograde neuronal tracer was deposited into auditory cortical areas including the primary auditory cortex (A1), second auditory cortex (A2), and posterior auditory field (PAF). Coronal sections were taken, and neurons showing positive retrograde labeling were counted and assigned to cortical and thalamic areas. Projections within and between sensory modalities were quantified; while some small-scale differences emerge, patterns of connectivity are overwhelmingly preserved across experimental groups within each cortical field examined. This structural preservation has implications for our understanding of the mechanisms that underlie crossmodal reorganization; moreover, it suggests that the connectivity necessary for resumption of auditory function may withstand even lengthy periods of deprivation.

3-I -134 Vocal pitch perception impairments might contribute to vocal emotion recognition difficulties in high-functioning autism spectrum disorder

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The ability to recognise the emotion of others by their tone of voice is critical for successful communication. People with an Autism Spectrum Disorder (ASD) have difficulties with vocal emotion perception. Currently it is unclear, whether these difficulties are associated with deficits in perceiving basic acoustic features of voices that are relevant for emotion perception. A key acoustic feature for vocal emotion perception is the fundamental frequency which is perceived as vocal pitch. Here we investigated, whether deficits in vocal pitch perception are associated with difficulties with vocal emotion perception in ASD. We tested vocal emotion recognition abilities in a group of adults with high-functioning ASD ($n = 16$; $IQ \geq 85$) and typically developed individuals ($n = 16$; matched pairwise on age, gender, and IQ). The ASD group has been previously shown to have difficulties in vocal pitch perception but intact non-vocal pitch perception abilities (Schelinski et al., Autism Research, 2016). The ASD group performed worse in vocal emotion recognition as compared to the control group. Within the control group, performance in the vocal emotion recognition test correlated with performance in vocal pitch, but not non-vocal pitch perception. Within the ASD group, there were no correlations between vocal emotion recognition and vocal or non-vocal pitch perception abilities. This indicated that in controls better vocal emotion recognition abilities were associated with better vocal pitch perception, but not in the ASD group. Additionally, lower vocal emotion recognition abilities were associated with higher extends of autistic traits in controls. Our results suggest that perceptual impairments, i.e. difficulties in vocal pitch perception might underlie difficulties in vocal emotion recognition in ASD. This implies that communication difficulties in ASD might not only be based on higher-level cognitive difficulties, but also on impaired basic perceptual processing.

3-I -135 Treating chronic tinnitus with neurofeedback

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Due to recent neurophysiological studies, subjective tinnitus has been associated with a change of ratio between differential EEG frequency modulations. While usually the slow delta- and the faster gamma-oscillations appear to be abnormally increased, alpha waves tend to be significantly suppressed for tinnitus sufferers, presumably in auditory regions. Application of neurofeedback treatment aiming for reversing these pathological activity patterns has formerly been proven successful for tinnitus treatment. However, while the standard neurofeedback approach only records data from a maximum of four electrodes, the recently developed tomographic neurofeedback uses 31 electrodes and source estimation algorithms (e.g. sLORETA) to modulate EEG activity with higher spatial resolution in distinct brain regions. In this project, we introduce a clinical study that evaluates sLORETA-based tomographic vs. standard neurofeedback for treatment of subjective tinnitus. Over the course of 15 weeks two groups of participants used neurofeedback to train an increase of (individual) alpha activity and a downregulation of delta power (3-4 Hz). While half of the participants (n=26) completed their training with the conventional protocol and thus did not modulate brain activity in a particular region, the remaining half (n=24) underwent tomographical training focusing on bilateral auditory cortex regions specifically. Preliminary data analysis indicates that both, tomographic and conventional, neurofeedback approaches resulted in improvements of subjective tinnitus symptoms measured by standard tinnitus questionnaires prior and after the training period. Neurofeedback and especially its spatially improved alternative can thus be considered as a highly promising form of therapy in the treatment of chronic tinnitus.

3-I -136 Neuronal plasticity in auditory cortex and brainstem after auditory deafferentation

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Auditory deafferentation induces plastic changes in many brain regions, including the auditory pathway. The change of neocortical activity and recruitment by the other sensory systems is a well-known neurological phenomenon which is occurred by intra- and cross- modal plasticity after sensory deprivation. Unilateral hearing loss was also affects the auditory system, and could evoke plastic changes, however, it was not evaluated yet fully. Here, we evaluate plastic change of neuron in inferior colliculus (IC) and auditory cortex (AC) after unilateral and bilateral deafness using an animal model. The structural changes of neuron after deafness were evaluated with dynamic change of non-phosphorylated neurofilament heavy change (NEFH), which was immunoreacted with SMI-32 monoclonal antibody, by western blot analysis. The mRNA expression level of NEFH was evaluated with RT-PCR in AC and IC, and by cell count of SMI-32-immunoreactive (-ir) neuronal population in IC. Deafness was induced by cochlear ablation bilaterally (BD) or unilaterally at right side (RD), and the brain tissues were harvested at 4 and 12 weeks after deafness. In AC, SMI-32 mRNA expression and SMI-32-ir protein levels were increased in the BD group. In particular, SMI-32-ir protein levels increased significantly 6 and 12 weeks after deafness was induced. In contrast, no significant changes were detected in the right or left auditory cortices at any time point in the UD group. In IC, The mRNA expression level of NEFH was not changed in BD and UD groups until 12 weeks after deafness at both side. However, in BD group, the ratio of SMI-32-ir neuron was increased at 4 weeks after deafness and western blot supported this finding. The ratio was return to normal level at 12 weeks after deafness. In UD group, no significant changes were identified.

3-I -137 Plasticity in cortical fast-spiking GABA networks supports recovered sensory processing following peripheral nerve injury

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The adult sensory cortex exhibits a remarkable plasticity following damage to sensory end organs. Afferent denervation results in a reorganization of cortical maps and changes in sensory capabilities. These compensatory adaptations have been associated with reduced GABA signaling and cortical hyperexcitability. However, it is unknown how functional modifications in sensory processing and dynamic changes in intracortical inhibition relate to one another during this process. Here, we directly measure changes in local inhibition and relate them to recovered auditory processing in putative pyramidal (PPy) neurons after extensive denervation. We made chronic recordings from individual PPy units in the ACtx of awake, head-fixed mice while optogenetically activating PV neurons for 8 weeks surrounding profound auditory nerve damage. This approach allowed us to compare distinct forms of plasticity, such as spontaneous-rate, sensory gain, PV-mediated inhibition and receptive field plasticity, in single PPy units with day-by-day resolution. We found that whereas the status of brainstem-evoked potentials and traditional biomarkers of central auditory hyperactivity did not predict the recovery of sensory responses, homeostatic adjustments in PV mediated inhibition during the first days following injury could predict the eventual recovery of cortical sound processing in PPy neurons weeks later. Our findings reveal striking inhibitory dynamics in the first week after auditory nerve injury but are agnostic as to whether these changes reflect postsynaptic changes in PPy neurons or changes in the PV networks themselves. Our ongoing experiments use chronic 2-photon calcium imaging to simultaneously visualize sound-evoked GCaMP signals in genetically identified PV neurons alongside neighboring PPy neurons. Collectively, our work identifies the central importance of rapidly releasing the PV plasticity 'brake' to enable recovered sensory processing in the adult cortex following injury.

3-J -145 Contribution of sequential comparison on lateralized activity in the human auditory cortex

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In the acoustic environment, information largely unfolds over time, e.g., in a sentence. The evaluation of such complex acoustic information requires that the successive segments within the event are analyzed. In order to identify meaningful changes over time, e.g., that the voice of a speaker rises during a sentence, fundamental features of the segments need to be compared. This requires continuous update of information in memory about the segments of the acoustic event. With a number of functional magnetic resonance imaging (fMRI) experiments, we investigated the effect of sequential comparison on the lateralization of processing in human auditory cortex and beyond. Specifically, we tested how the addition of sequential comparison effects the processing of direction of frequency modulation, intensity and duration. For the investigation, we used the contralateral noise procedure that is able to elucidate differential hemispheric contribution to the processing based on an increase in activity by presenting additional noise contralateral to the task-relevant stimuli. In accordance with previous studies, we found a strong involvement of the left auditory cortex during sequential comparison of sounds. In addition, the requirement of sequential comparison stronger involved areas in frontal and parietal cortex that are responsible for attention and working memory. We could show that some of these regions become stronger connected with the auditory cortex when sequential comparison is required. We think that the stronger demand on working memory and attention is caused by the sequential update of the reference for comparison in memory. Our findings may contribute to explaining the inconsistent results on hemispheric specialization of auditory processing in the literature since the tasks employed in the studies vastly differ with respect to the demand on sequential processing. Funding: German Research Foundation (DFG, AN 861/4-1, 2)

3-J -146 Transforming auditory information from learning experiences into lasting memories by removing an epigenetic brake on auditory system plasticity

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Auditory system plasticity is induced in adults when individuals learn from experiences with sound, such as learning associations between sound cues and their meaning. Induction of auditory cortical plasticity is correlated with the robustness of auditory memory over time and interference. Thus, an open question is how cortical contributions enable the maintenance of learned auditory information over time. Our approach to this question has been to investigate molecular processes that control gene expression events required for underlying plasticity in the formation and maintenance of memories. Since auditory memories have content, i.e., they are rich with detailed acoustic information about sounds and their links to meaning, we target how and when sound-specific neural representations (e.g., receptive fields) change with experience. Because inducing auditory system plasticity is essential for sound-specific memory formation, identifying critical neurobiological regulators of memory formation has broad implications for maintaining auditory cognitive health by enabling those mechanisms to induce plasticity when critical auditory information from experience needs to be maintained over time. Here, we report in rodent models that epigenetic contributions by histone deacetylase enzymes (HDACs) control gene expression for sensory cortical plasticity under experience-dependent conditions. HDACs are gate-keepers on memory formation, normally keeping molecular "brakes on plasticity" to prevent specific acoustic information from being consolidated into memory. Thus, HDAC-inhibitors have shown promise for initiating transcription-mediated changes in auditory system function and ultimately, auditory behavior. This work is potentially transformative for therapeutics to combine epigenetic drug targets with auditory training paradigms to "release the molecular brakes" and induce experience-dependent plasticity that enables highly specific acoustic information to maintain in memory.

3-J -147 MEG reveals neural correlates of successful "cocktail party" listening

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The ability to listen selectively to one out of several competing speech streams in a "cocktail party" situation is essential for successful communication in everyday life. Previous electrophysiological work in humans has demonstrated that competing speech streams are encoded individually at the level of auditory cortex. During selective listening, the representation of the attended speech stream is enhanced whereas neural responses to ignored streams are attenuated, so that the ongoing auditory cortex response is dominated by the attended stream. How differences in the cortical representation of attended and ignored speech streams relate to individual selective listening success is however not clear. Here we studied this question by combining behavioral measures of individual selective listening performance with MEG data obtained during a selective listening task, in which participants were asked to listen attentively to one out of two diotically presented speech streams. A stimulus reconstruction approach on the source level was used to reconstruct the envelope of attended and ignored speech stream from the ongoing MEG responses. The reconstruction accuracy served as a measure of the relative neural representation strength of the two streams in auditory cortex. MEG data obtained from 13 participants (8 female, 22±3 years) in auditory cortex show higher speech envelope reconstruction accuracies for the attended as compared to the ignored stream during selective listening, indicating an increased representation of the attended stream in auditory cortex. Surprisingly, selective listening performance correlated negatively with this representation bias, suggesting that a more balanced representation of both streams is beneficial for successful selective listening (r=.72, p=.006). A strong representation of ignored speech in auditory cortex may facilitate robust stream segregation and allow for a superior filtering of auditory information at higher processing stages.

3-J -148 Categorical memory representation in ferret auditory and frontal cortices

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Categorization can arise by grouping of sensory stimuli sharing perceptual similarity or by training in which sensory stimuli are assigned to behaviorally relevant classes associated with learned responses. Neuronal category representations have been previously identified in vision in prefrontal, inferotemporal and parietal cortices, but a clear demonstration in audition has been elusive. In previous work, we showed that ferrets could be trained to classify auditory stimuli distributed along continuous feature dimensions (e.g. frequency or amplitude modulation) into classes based on behavioral meaning (Go or No-Go). Here we explore how these categories become represented in different fields of ferret auditory cortex (A1 and secondary areas in dPEG) and frontal cortex (FC), when animals were passively listening to sounds or actively engaged in task. To investigate the underlying mechanisms of category representation, we distinguish between "category-selective coding" and "sensory-selective coding". Specifically, we expect stimuli from the same category to evoke shared response patterns across the neural population despite large sensory differences between them. Two metrics based on the Euclidean distance of the population response between stimulus pairs were computed to evaluate these categorical effects: (a) category index (CI), defined as difference between the mean distance of all pairs in which the stimuli from different categories and that the stimuli from same category; (b) the proportion of variance explained by categories (η^2). This analysis revealed that categorical information was observed in all regions during task performance, and the dynamics of this representation reveals that, the earliest categorical information emerged the earliest in FC, followed in dPEG, and then in A1. These results provide insight into how primary and secondary auditory cortices are deferentially involved in classifying acoustic inputs during active auditory memory retrieval.

3-K -150 Comparing human and nonhuman primate brain responses to auditory sequences using EEG

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Humans have the ability to perceive and move to the 'beat' in musical rhythms. This complex behaviour may be unique among primates, and involves extracting regularities from complex, non-isochronous auditory sequences and synchronizing movements to those regularities. To characterize cross-species differences in neural processing of rhythm and beat perception, we compared brain responses in humans and a macaque monkey using electroencephalography (EEG). EEG was recorded while participants listened passively to auditory sequences that consisted of white noise bursts (65ms) separated by intervals. Intervals were structured to create 5 types of sequences: i) isochronous (at three rates), ii) random, iii) strongly beat-based, iv) weakly beat-based, or v) non-beat-based. We compared the two species' evoked and induced responses in EEG, at various frequency bands (e.g., beta and gamma) to isochronous and random sequences, and compared neural entrainment at low-frequency (1-5 Hz) regularities in the structures of non-isochronous sequences (iii-v). Similarities and differences between species' brain responses reveal common and distinct aspects of neural processing of auditory sequences.

3-L -168 Dual-scale oscillatory mechanism for speech segmentation

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Speech consists of acoustic segments embedded within a rhythmic stream. Neural oscillations, which reflect high and low excitability states of the auditory cortex (AC) have been proposed as the driving mechanism behind the processing of incoming speech streams. Within this view, speech is segmented based on the oscillation timescales prior to higher-order processing. The empirical evidence to fully support this view is, however, inconclusive. Here we hypothesize that the segmentation mechanism of an individual's AC is tuned to the timescales of the smallest information carrying speech segments (either at the phonemic or syllabic timescale), and that the speech segmentation timescale (SSTS) at which the AC operates is reflected in the phase-locking ability (PLA) of the AC. To test this hypothesis we conducted two experiments in 19 normal-hearing subjects. First, using EEG we measured the PLA of the AC to 30 noise bands modulated between 0.5-20 Hz. Second, we measured the ability of each subject to process time-compressed speech. We time-compressed the LIST sentences corpus at 7 compression ratio's with the PSOLA algorithm and determined the speech intelligibility for each ratio. The combination of the two experiments allowed linking speech processing ability to the SSTS, as reflected in the PLA, in each individual. We found subject-dependent PLA patterns and speech intelligibility scores. The PLA corresponding to the phonemic (~50 ms) and syllabic timescale (240-400 ms), reflecting the individual's SSTS, was well correlated with the speech processing ability of fast speech. Subjects who had a preferred SSTS at the phonemic time-scale were less able to retrieve important information carrying features from continuous speech presented at fast rates compared to subjects with a preferred SSTS at the syllabic time-scale. This implies an early auditory processing stage that relies on a dual-scale segmentation mechanism for speech processing.

3-L -169 Temporal orienting and auditory frequency decoding: a human MEG/EEG study

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Temporal orienting improves sensory processing, akin to spatial attention. However, while spatial attention is selective - i.e., attended locations are prioritised at the cost of unattended locations - it is unclear whether temporal orienting shows a similar trade-off across time. Furthermore, while sustained attention to acoustic streams sharpens frequency tuning, it is unknown whether temporal orienting improves frequency tuning only at context-relevant time points. Thus, the aim of this study was to test whether frequency tuning in humans is modulated by temporal expectations. Healthy participants (N=24) performed an auditory discrimination task while their brain activity was measured using magneto- and electroencephalography (M/EEG). Acoustic stimulation consisted of sequences of brief pure tones (drawn randomly from 15 frequencies) interspersed with chords (drawn randomly from a set of two). In the rhythmic condition, chords were separated by a fixed 1 s interval, while in the jittered condition half of these intervals was random. Participants were asked to discriminate a subset of target chords, and the analysis of behavioural data revealed that chord predictability (rhythmicity) improved discrimination accuracy. In M/EEG analysis we focused on neural encoding of pure tones surrounding the non-target chords. To estimate frequency tuning and its changes over time, we used M/EEG-based auditory frequency decoding, whereby pair-wise Mahalanobis distances of all 15 frequencies formed a tuning curve with parameterised sharpness. Pure tones presented around the expected chord onset showed sharper tuning in the rhythmic condition than in the jittered condition, suggesting that temporal orienting sharpens frequency tuning at context-relevant time points. Crucially, pure tones presented further away from the expected chord onset showed the opposite effect on frequency tuning, suggesting a trade-off in frequency encoding induced by temporal orienting.

3-L -170 Spectrotemporal receptive fields in mouse primary auditory cortex

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Neurons in the central auditory system often exhibit non-linear responses to both simple and complex sound stimulation. Such nonlinearity can be well illustrated by the spectrotemporal receptive field (STRF). This study was to characterize the spectrotemporal pattern of the cortical neurons in the C57 mice. Extracellular responses to a simple and multiple frequency (sFreq and mFreq) gamma tone stimulus were recorded from the layer III/IV of the primary auditory cortex. Neuronal STRFs were constructed based on their responses to tones at 50 dB SPL. The excitatory bandwidth, lateral inhibition and post-excitation suppression were analyzed across neurons. Our data show that the STRF bandwidths to mFreq were significantly shorter than those to sFreq. The presence of lateral and surround inhibition in higher auditory areas is well documented. STRFs obtained from multi-frequency stimuli have shown excitatory as well as the inhibitory effects of auditory neurons as compared to the sFreq stimuli. Similar to those studies we found lateral inhibition areas and post-excitation suppression areas were more noticeable in mFreq STRF. The lateral inhibition area was identified in 22% sampled neurons and the post-activation suppression in 66% neurons. Our data suggest that cortical neurons behaved differently in response to sFreq and mFreq stimuli. The auditory cortex had better spectral and temporal coding of mFreq acoustic signals. These finding were similar to those obtained from cat and monkey auditory cortices, suggesting that cortical mechanism for spectrotemporal information processing can be sharable across species.

3-L -171 Does sensory cortex use the most predictive neural code?

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Why do neurons in sensory systems represent the natural world in the way that they do? Neurons in primary sensory cortex respond to a diverse range of features in dynamic natural scenes. For example, in the primary auditory cortex (A1) a neuron might respond selectively to a brief high or low frequency sound. Likewise, a neuron in primary visual cortex (V1) might be selective for a flashing vertical bar or for an edge moving diagonally. Various normative approaches can account for certain features of representations in these cortical regions. Here we explore the normative principle that the cortex represents natural stimuli by responding selectively to those features in the recent past of sensory input that best predict the immediate future sensory input. We tested this hypothesis using a simple feedforward neural network and show that even optimising this restricted model for prediction of future stimuli produces units whose receptive fields closely resemble those of neurons in primary visual and auditory cortex. This inludes the spatial response properties of neurons in V1 and the frequency properties of those in A1, and also, most notably their temporal tuning properties in both. Furthermore, among the many network configurations we examined, the networks that predicted best also produced units whose response properties most resemble the neural data. This suggests that sensory processing may be optimised to extract those features with the most capacity to predict future input.

3-L -172 The challenging recognition of emotions from whispered voices

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Recognizing emotional signals in our social and natural environments is important for adaptive behavior. In humans, these emotional signals are expressed and recognized in many sensory channels, but specifically also in vocal signals. Recent studies identified a distributed network of brain areas underlying the perception of vocal emotions in normally phonated vocalizations. However, vocal emotions are sometimes and in certain contexts also expressed in a whispered tone, such as a fearful whisper in a threatening environment. Here, I will present new data about how the neural system recognizes emotions from whispered vocalizations. Whispered vocalizations are extremely impoverished in terms of their acoustic quality (i.e. the breathiness of whispering), thus imposing an extreme challenge to the human neural system to accurately perceive emotions expressed in this voices. Our data show, first, that emotions from normal voices are decoded in regions of the auditory cortex that mainly decode spectral voice information based on the salient pitch information in normal voices. Second, emotions from whispered voices seem to be decoded in a compensatory neural network largely outside the core auditory system in frontal brain regions and in higher-level auditory regions that mainly decode temporal voice information as the only available information in whispered voices. Third, based on a connectivity analysis we also have shown that recognizing emotions from whispered voices requires information exchange in a complex and large-scale neural network. Taken together, emotions can be recognized from whispered voices, although less accurate and only at the costs of considerably neural compensation mechanisms.

3-L -173 Encoding of dynamic ripple mixtures in human auditory cortex using 7T fMRI

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Modulation transfer functions calculated from dynamic ripples have been shown to differ from those calculated from natural sounds. Here, we collected fMRI responses to 8 simple ripples and their pairwise mixtures to investigate the neural encoding of spectro-temporal modulations. An encoding analysis was performed to identify voxels whose response could be modelled as a linear function of the ripple parameters: fundamental frequency, temporal modulation rate, and spectral scale. The 12 runs were

partitioned into various train and test sets to assess generalizability: Train simple: Train on all simple runs, test on all mixed runs; Train mixed: Train on all mixed runs, test on all simple runs; Even: Train and test on even distribution of simple and mixed runs; Simple only: Train on 5 simple runs, test on 1 held out simple run; Mixed only: Train on 3 mixed runs, test on 3 held out mixed runs. Model performance per voxel was calculated as the Pearson correlation between the true and the predicted response to the test sounds. Permutations were used to calculate an empirical null distribution and correct for multiple comparisons. Performance was better than chance in only one subject, where significant voxels for all train-test configurations concentrated in the first transverse sulcus of the right hemisphere. Voxels predicted well in the train simple and train mixed configurations overlapped nearly exactly, while some voxels were only predicted well in the even and simple only configurations. Our encoding analysis revealed that responses could only be predicted as a linear combination of ripple parameters in one of our six subjects. This is surprising given that responses were well predicted by decompositions of natural sounds into frequency-specific joint spectro-temporal modulations in similar experiments. Ongoing analyses will determine whether this result reflects low SNR or a distributed, non-linear relationship between simple and mixed ripples.

3-L -174 Integrating behavioral context into auditory encoding models

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Sensory encoding models that incorporate nonlinear adaptation and/or gain control have been shown to predict cortical responses to natural sounds better than the linear spectro-temporal receptive field (STRF). It has also been established that changing behavioral state, by engagement in auditory task or switching between tasks, can influence linear STRF fits. However, less is known about how the more comprehensive nonlinear encoding models are influenced by changes in behavioral state. This problem is challenging because fitting nonlinear models require large quantities of neurophysiological data but data are often limited in studies of behaving animals. To measure behavior-dependent changes in nonlinear auditory encoding, we developed a computational framework for unbiased comparison of a large number of encoding models. We identify models with minimal complexity, i.e., those which require as few free parameters as possible but are still able to optimally account for neural responses. We analyzed single-unit data collected from primary auditory cortex of awake ferrets while they switched between passive listening and a tone detection task. We identified optimal parameterizations and found that a nonlinearity modeling short-term synaptic plasticity accounted for most nonlinear response properties across the models tested. We then fit models using stepwise regression, in which individual free parameters were either fixed across behavioral states or allowed to vary between states. The majority of behavior-dependent changes in encoding occurred in spectral tuning and/or the static nonlinearity. Allowing temporal filter properties and nonlinear adaptation to vary between behavior states did not provide additional improvement in performance. These findings suggest that behavioral state primarily impacts cortical spectral tuning and excitability, while having relatively little impact on adaptation and temporal filtering properties.

3-L -175 Attentional effects on neural responses in a cocktail party model in the ferret auditory cortex

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During the cascade of neural responses triggered by sound from multiple sources hitting the tympanum, the brain needs to deconstruct the mixture by auditory scene analysis into different streams and then select the most relevant streams for further processing. Many different ideas have been proposed as to how the brain segregates sound and decodes the auditory scene, some suggesting that scene segregation is pre-attentive, activating separate neural populations that respond to different auditory attributes, while others emphasizing the importance of attention. Ferrets are an excellent animal model to study speech representation because their hearing is similar to humans, their Auditory Cortex (AC) is complex enough to encode phoneme classes (Mesgarani et al., 2008) and they can be trained to differentiate syllable sequences (Bizley et al., 2015; Duque et al., 2016). To explore the neural mechanisms of stream segregation, we trained ferrets to discriminate tri-syllabic pseudo-words using a conditioned avoidance GO/NO-GO task. We also trained them to attend to a target word (Eg. FA-BE-KU) by a female speaker while ignoring a simultaneous male background speaker. In order to analyze neural encoding in stream segregation we recorded in primary and secondary areas of AC. We explored whether responses during the tasks showed adaptively enhanced representation of the attended female speaker. Preliminary neurophysiological data indicate that neuronal responses to words in the male distractor voice in the cocktail party scenario showed specific suppression, enhancing representation of the attended female target word. This study shows that neurons in higher order AC can encode pseudo-words selectively, even in a multi-talker scenario. These results will help us understand the neural basis for representation of complex sound sequences and yield deeper insight into neural mechanisms underlying initial stages in human speech processing of the cocktail party problem.