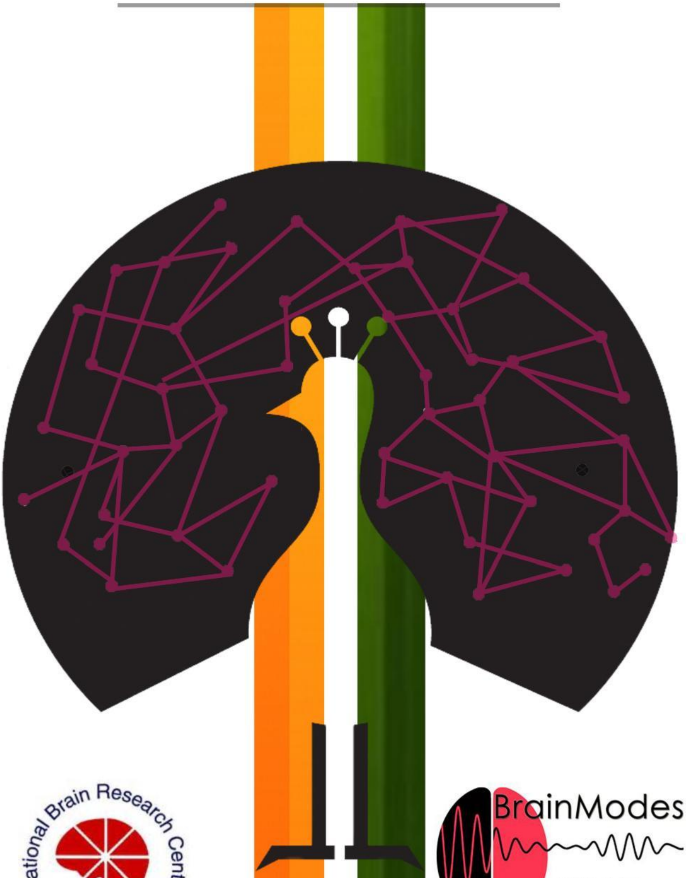

National Brain Research Centre
NBRC

# BrainModes 2017

Hosted by
National Brain Research Centre

Designed by Shiladitya Laskar

| Time | Title | Speaker |
| --- | --- | --- |
| | **Day 1: Pre-Symposium Workshop 11-Dec-2017** | |
| 09:30 | Introduction to Pre-symposium workshop | Dipanjan Roy |
| 09:45 | Understanding cognition from brain oscillations | Arpan Banerjee |
| 10:45 | **Tea/ Coffee Break** | |
| 11:00 | Computational Neurology and Large-scale models | Dipanjan Roy |
| 12:00 | Network models of disease/ Computational Models and tools | Markus Butz-Ostendorf |
| 13:00 | **Lunch Break** | |
| 14:00 | fMRI Experimental design and analysis | Dipanjan Ray |
| 15:00 | **Tea/ Coffee Break** | |
| 15:30 | Integrative methods for clinics/Rehabilitation and low cost intervention | Tapan Gandhi |
| 16:30 | Brain oscillations from MEG | Peter Uhlaas |
| | **End of the day** | |
| | **Day 2: Pre-Symposium Workshop 12-Dec-2017** | |
| 09:30 | Granger causality methods and applications to neuroscience data | Mukesh Dhamala |
| 10:30 | Network models of disease/ Macroscopic models of EEG | Peter Robinson |
| 11:30 | **Tea/ Coffee Break** | |
| 12:00 | Spike-LFP recordings | Supratim Ray |
| 13:00 | **Lunch** | |
| 14:00 | Live Demo fNIRS/EEG/ TMS | Aerobe |
| 16.00 | **Coffee Break** | |
| 16:30 | The Virtual Brain | Viktor Jirsa |
| | **End of the day** | |
| | **Venue: NBRC Main Auditorium** | |

| Time | Title | Speaker |
|---|---|---|
| | **Day 3: Symposium 13-Dec-2017** | |
| 09:00 | Introducing Speakers/BrainModes-17 | Dipanjan Roy and Arpan Banerjee |
| 09:05 | **Welcome Address by Secretary DBT/ Director NBRC** | |
| 09:30 | **Tea/ Coffee** | |
| 09:40 | Brain Network identification and analysis/Dynamic Causal Models Revisited | Karl Friston |
| 10:20 | Longitudinal dynamic causal models over different timescale | Danielle Marinazzo |
| 11:00 | Beyond Connection Matrices: Brain Modes based Analysis of Structure and Function | Peter Robinson |
| **11:40** | **Tea/ Coffee** | |
| 11:50 | Wired for music? – a diffusion MRI based study of normative music perception skills | Nandini Chatterjee Singh |
| 12:30 | The volatility theory of schizophrenia | Micheal Breakspear |
| 13:10 | **Lunch Break + Poster** | |
| 13:45 | **Poster Session** | |
| 15:00 | Understanding the role of gamma oscillations in cortical processing | Supratim Ray |
| 15:40 | The phenomenon of emergence in oscillatory brain networks | Viktor Jirsa |
| **16:20** | **Tea/ Coffee** | |
| 16:30 | Neural Synchronization in Motor Control | Andreas Daffertshoffer |
| 17:10 | Bridging multiple scales in the brain using personalized brain network modelling | Petra Ritter |
| 17:50 | Oscillations and Neuronal Dynamics in Schizophrenia | Peter Uhlhaas |
| 18:30 | Dance of mirror neurons | Swati Mohan |
| **19:30** | **BANQUET DINNER** | |
| | **Venue: Savoy Suites Manesar** | |

| Time | Title | Speaker |
| --- | --- | --- |
| | **Day 4 : Symposium 14-Dec-2017** | |
| 09:00 | Early organization and development of the visual pathways | Ghislaine Dehaene |
| 09:40 | Experience and age dependent development of neural representations | Brigitte Roeder |
| 10:20 | Crossmodal plasticity: Recycling pre-existing neural and computational architecture? | Olivier Collignon |
| **11:00** | **Tea/ Coffee** | |
| 11:30 | Brain network oscillations during perceptual decision-making | Mukesh Dhamala |
| 12:10 | Linking macroscopic brain connectivity and intrinsic brain architecture | Claus Hilgetag |
| 12:50 | A novel approach to dynamically connect the patient's connectome to genomics and simulation | Markus Butz-Ostendorf |
| **13:30** | **Lunch Break + Poster** | |
| **14:15** | **Poster Session** | |
| 15:30 | Language Distance Drives Adaptive Effects in the Anterior Cingulate Cortex | Brendan Weekes |
| 16:10 | Lanuguage development, higher order cognition/Tree structures and human singularity: brain mechanisms of syntax in language and math | Stanislas Dehaene |
| 16:50 | Concluding remarks and BM-18 host announcement | Arpan Banerjee and Dipanjan Roy |
| **19:30** | **Neuroscience Social** | |

# Abstracts of Lectures

Michael Breakspear
Queensland Institute of Medical Research,
Brisbane QLD 4029, Australia

**The volatility theory of schizophrenia**

Brain structure reflects the influence of evolutionary processes that pit the costs of anatomical wiring against the computational advantages conferred by complexity. The processes shaping this exchange remain poorly understood. We address this problem by studying random variants of the human connectome that perturb network topology while preserving the wiring length of the brain. We first show that the presence of hubs that are distributed widely through cortical regions confers a wiring cost that the brain minimizes. However, when challenged with network perturbations, inter-hemispheric links to prefrontal hubs quickly disconnect and yield daughter networks that differ substantially from one another. When variations in structure are allowed to accumulate, strong peripheral connections progressively connect to central nodes and hubs shift toward the middle of the brain. Progressive randomization of brain networks also leads to a topologically unstable regime consistent with a phase transition in complex systems. Intriguingly, the fragility of hubs to perturbation is significantly correlated with the acceleration of grey matter loss in schizophrenia. Together with wiring cost, we suggest that fragile prefrontal hub connections and topological instabilities act as evolutionary influences on complex brain networks whose set point may be perturbed in neurological and psychiatric disorders.

Markus Butz-Ostendorf
Biomax Informatics AG, Planegg,
Germany

**A novel approach to dynamically connect the patient's connectome to genomics and simulation**

The adult brain is not as hard-wired as traditionally thought. The brain constantly forms new connections and breaks existing ones. Especially after lesions, this so-called structural plasticity is significantly enhanced and may contribute to the functional reorganization of remaining brain networks. Although structural plasticity after brain lesions is known since the late 1960ies, its driving forces are still not fully understood. We postulate that the formation and deletion of synapses after brain lesions is driven by the need of each neuron to maintain its electrical activity at a homeostatic setpoint (van Ooyen and Butz, 2017). Brain lesions cause a significant distortion of activity homeostasis in down-stream areas and neurons aim to restore an equilibrated activity by rewiring their synaptic connections. We tested this hypothesis by model simulations („Model of Structural Plasticity“) against focal retinal lesion studies in mice. We found surprising similarities between the animal model and the simulation in the time course of spine dynamics, loss and gain of connectivity and activity restoration (Butz and van Ooyen, 2013). We also found similarities between human brains rewiring after stroke and the simulation model (Butz et al. 2014): Brain network topology overall becomes more random after lesion-induced rewiring while brain areas compensating a loss of input increase their betweenness centrality. It is now at the time to test predictions from the simulation model against data from individual patients. We introduce NeuroXM™ a novel platform that enables us to run brain simulations based on measured brain connectivity of individual patients. We will discuss the capabilities of brain simulations for designing personalized treatment plans in neurology.

Nandini Chatterjee Singh
National Brain Research Centre, Manesar
Haryana, India

**Wired for music? – a diffusion MRI based study of normative music perception skills**

*Archith Rajan, Jacob Antony Alappatt, Apurva Shah, Megha Sharda, Jeffrey M Valla, Madhura Ingalhalikar and Nandini C Singh*

Music is not only an important social, emotional and communicative stimulus, but in recent years musical training has provided fertile ground for studying neuroplasticity in the brain.

Consequently, while much is now known about how musical training influences brain structure and organization, music perception abilities are not very well understood. Music perception skills can be independent of musical training. The objective of the current study was to study the normative variation of different musical perception skills in an adult population and their subsequent correlation with white matter structure and organization. White matter organization has recently emerged as a useful neurobiological marker of subtle differences in behavior.

We assessed normative variation of music perception skills in adult population (N=29) by the PROMS-S musicality test. Tract based spatial statistics (TBSS) on high angular diffusion data revealed negative associations between Mode of Anisotropy and d’ measures of total scores, sub-scores of Accent, Embedded Rhythms and Tempo in the corpus callosum extending to Corona Radiata. Partial volumes of secondary fiber population also correlated positively with behavioural performance. In combination, our results suggest that increased inter-hemispheric connections between auditory and motor areas might be characterize enhanced music perception, particularly in the temporal domain, independent of training.

Olivier Collignon
Center for Mind/Brain Sciences (CIMeC), University of Trento, Italy
University of Louvain, Belgium

**Crossmodal plasticity: Recycling pre-existing neural and computational architecture?**

Studies in early blind people provide important insights into the interaction between experience and intrinsic biological constraints in shaping the development of the sensory and cognitive brain regions. In early blind, occipital regions massively enhance their response to non-visual inputs. But what are the mechanisms guiding this crossmodal reorganization process? It was suggested that these neuroplastic changes are constrained by the native functional organization of the occipital cortex. In contrast to this view, other studies suggest that the occipital cortex is recruited in the blind by higher-level cognitive operations that have little to do with native occipital functions such as memory, language processing or numerical thinking. In the talk, I will intend to reconcile these two apparently contradicting views of the mechanisms governing crossmodal plasticity by making the hypothesis that the recruitment of the occipital cortex in early blind individuals by higher-level cognitive functions also link to the intrinsic computational role of specific regions. However, I will also illustrate how the fact that crossmodal plasticity may recycle the pre-existing neural and computational architecture of occipital regions does not mean that these regions are amodal or abstracted from sensory input and experience.

Andreas Daffertshofer
Institute of Brain and Behavior
MOVE Research Institute, Vrije Universiteit
Amsterdam, Netherland

**Phase description of coupled neural oscillators**

Rhythms and oscillatory behavior are abundant on all different scales of the human brain. Meso- and macroscopic models as well as instrumental devices and recording techniques have been developed to describe and trace these, typically large-scale brain dynamics. However, linking recordings of brain activity to the underlying neuronal mechanisms is one of the major challenges in neuroscience. A promising idea is to recover the macroscopic behavior by simulating neural network models. Such modeling is often simplified to the phase dynamics of cortical activity, which is believed to play a crucial role in information processing and inter-cortical communication. Time series analysis techniques can often be applied to extract the phase dynamics of the model which render the comparison between experimental and simulated data feasible. But does the phase dynamics really represent the underlying neural network? We compared the outcome of several mathematically sound phase reduction techniques applied to networks of weakly coupled Wilson-Cowan neural masses. While some reduction techniques only differ quantitatively, others yield qualitatively different phase models. By 'qualitatively different' we mean that the models display distinct stability properties. We highlight caveats and sensitive issues in the analytic derivation of phase models that may contribute to these dichotomies. We also illustrate the effects using numerical simulations. It appears phase reduction techniques have to be tailored to the targeted macroscopic observable and the parameter regime under study. More importantly, though, we have to conclude that using heuristic phase models as guidelines for inferring neural network dynamics from data is challenging, if at all possible.

Stanislas Dehaene
Neurospin-Cognitive Neuroimaging Unit
College de France, France

**Tree structures and human singularity: brain mechanisms of syntax in language and math**

Is the human brain endowed with a specific ability for the mental representation of nested, tree-like structures? And is a single brain circuit involved in representing such structures in natural language and in mathematics? In the first part of the talk, I will present converging evidence that the left posterior superior temporal sulcus (pSTS) and inferior frontal gyrus (IFG, pars triangularis and orbitalis) play a central role in the syntax of spoken and written natural languages. Intracranial recordings indicate that, within these regions, high-gamma signals track the nested structure of linguistic constituents. In the second part, I will present fMRI studies investigating whether these brain areas also contribute to various aspects of mathematics. When professional mathematicians reflect upon high-level mathematical concepts in algebra, analysis, geometry or topology, the activation spares classical language areas. Instead, high-level mathematics involves bilateral intraparietal areas involved in elementary number sense and simple arithmetic, and bilateral infero-temporal areas involved in processing Arabic numerals. The evidence suggests that the acquisition of mathematical concepts recycles areas involved in elementary number processing. My conclusion will be that human brains are attuned to many different languages – spoken, written, mathematical, musical... – and that brain evolution may have endowed the human brain with a widespread ability to manipulate nested syntactic structures in most, if not all domains of human cognition.

Ghislaine Dehaene-Lambertz
Cognitive Neuroimaging Unit, INSERM
France

**Early organization and development of the visual pathways in human infants**

In both human and non-human primates, the ventral visual cortex comprises multiple specialized subregions that are involved in the visual recognition of image categories such as objects, faces or places remarkably similar across individuals despite differences in cultural, linguistic, or socio-economic background. Even for culturally learned skills such as reading, similarly-localized activations are observed across writing systems and ages of acquisition revealing the weight of structural constraints on functional architecture. In this talk, we will examine how an early developing cognitive function, face recognition and a cultural acquisition, reading, settled in the ventral visual cortex, how they interact and what these observations teach us about human brain plasticity.

Mukesh Dhamala
GSU Neuroscience Institute, CBN, CENO, CDT and CABI
Georgia State University, Atlanta, USA

**Brain network oscillations during perceptual decision-making**

Synchronized neuronal oscillations and oscillatory interactions within distributed brain regions are known to be central to normal perceptual and cognitive functions. Here, using human scalp electroencephalography (EEG) recordings combined with source reconstruction techniques, we study how oscillatory activity functionally organizes different neocortical regions during various perceptual decision-making tasks. We uncover that beta (~15 Hz) and gamma (~80 Hz) frequency network oscillations commonly mediate sensory and cognitive processing to arrive at perceptual decisions in various sensory domains. The findings of times and frequencies of oscillatory interactions in sub-networks further provide us new insights into the general mechanisms for sensory information-guided, goal-directed behaviors, including perceptual decision-making.

Karl Friston
Institute of Neurology, University College London, U.K

**Dynamic causal modelling revisited**

Dynamic causal modelling is now fairly established in the estimation of brain coupling, in terms of dynamic or contextual changes in effective connectivity. I will revisit the dynamic causal modelling of fMRI timeseries by asking whether we can take the modelling of neuronal dynamics to the next level – using neural mass models based on the canonical microcircuit. This furnishes generative or dynamic causal models of haemodynamic responses that can also generate electrophysiological measurements. In principle, this allows the fusion of haemodynamic and electrophysiological responses. Furthermore, it enables Bayesian model comparison of competing hypotheses about physiologically plausible synaptic effects; for example, does attentional modulation act on superficial or deep pyramidal cells – or both? I hope to describe the resulting dynamic causal model and provide an illustrative analysis of attention to visual motion. I will also try to answer long-standing questions in fMRI; for example, do haemodynamic responses reflect extrinsic (afferent) input from distant cortical regions, or do they reflect intrinsic (recurrent) neuronal activity? To what extent do inhibitory interneurons contribute to neurovascular coupling? What is the relationship between haemodynamic responses and the frequency of induced neuronal activity? This presentation does not pretend to answer these questions; rather show how they can be addressed using neural mass models of fMRI timeseries.

Claus Hilgetag
University Medical Center Hamburg-Eppendorf (UKE) Germany

**Linking macroscopic brain connectivity and intrinsic brain architecture**

The connections that link neurons within as well as between cerebral cortical areas form a multi-scale structural network for communication in the brain. Which principles underlie the organisation of this complex network? Recent work has addressed this question by systematically investigating the relation of essential features of cortico-cortical connections, such as their presence or absence as well as patterns of laminar projection origins and terminations, to fundamental structural parameters of cortical areas, such as their distance, similarity in cortical cytoarchitecture as defined by cortical lamination or neuronal density, as well as similarity in macroscopic and microscopic morphological features. These systematic analyses demonstrate the presence of an architectural type principle of cortical connections. Across different species (primate, cat, mouse, human) and different cortical lobes, the essential features of cortico-cortical connections vary consistently and strongly with the cytoarchitectonic similarity of cortical areas. By contrast, such relations were not found consistently for distance, similarity of cortical thickness or cellular morphological features. Moreover, intrinsic brain architecture as characterised by architectural type and neural density also accounted for cellular neuronal features, such as cell size or shape. The robustness of the findings across mammalian brains allows direct cross-species predictions of the existence and laminar patterns of projections, including for the human brain, where such data are not directly available experimentally. Cortical gradients in architectural types also determine the specific organisation of the local micro-circuits of different areas. Therefore, these findings illuminate a general principle of neural wiring, linking the organization of macroscopic cortical connections to intrinsic circuits of the cerebral cortex. This architectonic type principle integrates cortical connectivity and architecture across scales of organisation, with implications for cortical physiology as well as for developmental mechanisms.

Viktor Jirsa
Institute de Neurosciences des Systèmes, CNRS, Marseille
France

**The phenomenon of emergence in oscillatory brain networks**

In order to maintain brain function, neural activity needs to be tightly coordinated within the brain network. How this coordination is achieved and related to behavior is largely unknown. It has been previously argued that the study of the link between brain and behavior is impossible without a guiding vision. Here we propose behavioral-level concepts and mechanisms embodied as structured flows on manifold (SFM) that provide a formal description of behavior as a low-dimensional process emerging from a network's dynamics dependent on the symmetry and invariance properties of the network connectivity. Specifically, we demonstrate that the symmetry breaking of network connectivity constitutes a timescale hierarchy resulting in the emergence of an attractive functional subspace. We show that behavior emerges when appropriate conditions imposed upon the couplings are satisfied, justifying the conductance-based nature of synaptic couplings. Our concepts propose design principles for networks predicting how behavior and task rules are represented in real neural circuits and open new avenues for the analyses of neural data.

Daniele Marinazzo
Department of Data Analysis, University of Ghent, Belgium

**Longitudinal dynamic causal models over different timescales**

Dynamic causal models are a powerful tool to investigate the presence and nature of connections between and within neural populations, and their modulations. Usually these modulations are induced by a task or an intervention. Here on the other hand I will present a framework in which modulations in time are investigated. Applications will cover different time scales (seconds to months), neuroimaging modalities (EEG, ECoG, fMRI), and species (humans and rats).

Supratim Ray
Centre for Neuroscience, Indian Institute of Science
Bengaluru, India

**Understanding the role of gamma oscillations in cortical processing**

Brain signals often show oscillations at different frequencies, which are tightly coupled to different behavioral states. We are interested in a high-frequency rhythm called “gamma” (30-80 Hz), which is modulated by high-level cognitive processes such as attention, memory, and meditation, and is also highly dependent on the properties of the visual stimulus. In the first part, I will discuss some characteristics of gamma oscillations, in particular how varying the orientation, size and color of the stimulus can modulate gamma oscillations. In the second part, I will describe our recording setup to simultaneously record spikes, local field potential (LFP), electrocorticogram (ECoG) and electroencephalogram (EEG), which represent neural processing at four different levels, and discuss our efforts to understand the properties of these brain signals.

Petra Ritter
Department of Brain Simulation,
Department of Neurology, Charité University Medicine Berlin
Berlin Institute of Health Berlin, Germany

**Inferring multi-scale neural mechanisms with brain network modelling**

I will talk about advances of the neuroinformatics platform The Virtual Brain (thevirtualbrain.org) to integrate experimental findings with subject-specific multi-scale whole-brain network models. The Virtual Brain models enable the integration of empirical results into a biophysically based framework that allows the systematic testing of the mutual compatibility of the identified mechanisms in the context of full-brain network interaction and the prediction of system-level processes emerging from the coalescence of the individual identified mechanisms. I will demonstrate how cross-species integration may provide evidence for possibly optimal computational principles.

Peter Robinson
Centre for Integrated Research and Understanding of Sleep
School of Physics, University of Sydney, Australia

**Beyond Connection Matrices: Brain Modes and Physically Based Analysis of Structure and Function**

The brain is a multiscale physical system, whose most essential dynamics are encapsulated in the natural modes of its dynamics. Here, we show how these modes can be used to understand both brain dynamics and connectivity from a quantitative physical basis. This avoids use of inappropriate graph-theoretic approaches that often fail to incorporate the brain's geometry and other physical characteristics, and which are correspondingly divorced from the physical brain. Eigenmode approaches enable functional connectivity to be quantitatively calculated from effective connectivity, and vice-versa, including time dependences and geometry, and are found to be closely connected to neural field theory and system transfer functions.

Brigitte Röder
Biological Psychology and Neuropsychology, University of Hamburg, Hamburg, Germany

**Experience and age dependent development of neural representations**

Learning at the beginning of the ontogenetic development must be to a larger degree bottom-up driven since internal models of the world do not yet exist. Later learning, in contrast, should be more dependent on top-down mechanisms which guarantee a controlled modulation of internal representations. We demonstrated that infants quickly learn crossmodal statistics in passive exposure settings. By contrast, adults seem to learn them only if they are task relevant. We propose that the change in learning mode causes sensitive periods. We showed that what humans learned within the sensitive period seems to be at least partially conserved. For example, restoring vision after a congenital blindness is not followed by a complete loss of crossmodal compensation in auditory motion processing and related neural adaptations. Only partial visual recovery, e.g. in global motion processing seems linked to an incomplete development of visual representations.

Peter Uhlhaas
Centre for Cognitive Neuroimaging School, University of Glasgow, Glasgow, U.K

**Oscillations and Neuronal Dynamics in Schizophrenia**

A considerable body of work over the last 10 years combining non-invasive-electrophysiology (electroencephalography/magnetoencephalography) in patient populations with preclinical research has contributed to the conceptualization of schizophrenia as a disorder associated with aberrant neural dynamics and disturbances in excitation/inhibition (E/I) balance parameters. Specifically, I will propose that recent technological and analytic advances in MEG provide novel opportunities to address these fundamental questions as well as establish important links with translational research.

We have carried out several studies which have tested the importance of neural oscillations in the pathophysiology of schizophrenia through a combination of MEG-measurements in ScZ-patients and pharmacological manipulations in healthy volunteers which target the NMDA-receptor. These results highlight a pronounced impairment in high-frequency activity in both chronic and unmedicated patients which could provide novel insights into basic circuit mechanisms underlying cognitive and perceptual dysfunctions.

Our recent work has employed MEG to understand the developmental trajectory of neural oscillations during adolescence and the possibility to develop a biomarker for early detection and diagnosis of ScZ. We found marked changes in the amplitude of high-frequency oscillations and synchrony that were particularly pronounced during the transition from adolescence to adulthood. Moreover, data from participants meeting ultra-high risk criteria for psychosis suggest that signatures of aberrant neuronal dynamics are already present prior to the onset of psychosis, highlighting the importance of advancing biomarkers for early intervention and diagnosis.

Brendan Weekes
Professor and Chair in Communication Science, The University of Hong Kong, Hong Kong

**Language Distance Drives Adaptive Effects in the Anterior Cingulate Cortex**

The Adaptive Control (AC) model (Green & Abutalebi, 2013) assumes that language output in bilingual speakers requires a network of language control at the neural level that engages with the anterior cingulate cortex (ACC). We reasoned that linguistic similarity should influence ACC activity due to differential demands placed on language control processes. To test this hypothesis, we presented a word translation task using an er-fMRI design to bilingual/bi-scriptal participants whose native language is different to English but who read in a similar or different type of script: Dutch-English (related language family/related script), Hindi-English (related language family/ unrelated script) and Cantonese-English (unrelated language family/unrelated script). Following the AC model, we predicted that bilinguals reading linguistically related languages and similar scripts will engage the ACC differently to bilinguals reading linguistically related languages but unrelated scripts and linguistically unrelated languages but unrelated scripts. As predicted, ACC activity varied during word translation according to linguistic similarity: Dutch-English speakers who read identical scripts engage the ACC more than both Hindi-English and Cantonese-English speakers who did not differ. We contend that this is the first neuroimaging evidence to show that language similarity influences conflict monitoring in the bilingual brain. Critically, it is similarity in the type of script not spoken language family similarity that predicts ACC activity. The results have implications for theoretical models of bilingual language processing at the behavioural and neural level in bilinguals. Adaptive control in translation is strongest if a bilingual speaker uses a similar language with an identical script compared to when the language and script are different.

# Abstracts of Posters

**Eigenmode analysis of spherical brain activity via neural field theory**

K. N. Mukta, J. N. MacLaurin, P. A. Robinson

*School of Physics, University of Sydney, New South Wales 2006, Australia*

Corticothalamic neural field theory (NFT) has successfully explained a wide variety of phenomena, ranging from EEG spectra and evoked potentials to nonlinear phenomena such as seizures and Parkinsonian oscillations. NFT has also been used to understand brain connectivities and its eigenmodes have been employed to solve the inverse problem of determining brain structure from functional connectivity. Most recently, its unihemispheric eigenmodes have been shown to be remarkably similar to spherical harmonics in structure. They are also the building blocks for bihemispheric modes, whose structure and symmetry properties explain many features of resting state and task-related activity. This eigenmode expansion is of use because it helps us understand the dynamics of the brain's activity in terms of its natural modes. Here, corticothalamic NFT is analyzed on a sphere and used to derive the transfer function, the power spectrum, the correlation function, and the cross spectrum in terms of spherical harmonics. The results are analyzed and compared with planar NFT in both finite and infinite geometries. The results of spherical and finite-planar geometries converge to the infinite-planar geometry in the limit of large brain size. The main effects of the spherical modal structure are explored, particularly to understand the number of modes that contribute significantly to these observable quantities and the effects of the finite spatial extent of the cortex. Key results are that when we truncate the modal series it is found that, for physiology plausible parameters, only the lowest few spatial eigenmodes are needed for an accurate representation of macroscopic brain activity. Cortical modal effects can lead to a double alpha peak structure in the power spectrum, although the main determinant of the alpha peak is corticothalamic feedback. In the spherical geometry, the coherence function between points decays monotonically as their separation increases at a fixed frequency, but persists further at resonant frequencies. The correlation between two points is found to be positive, regardless of the time lag and spatial separation, but decays monotonically as the separation increases at fixed time lag. At fixed distance the correlation has peaks at multiples of the period of the dominant frequency of system activity. This analysis of physiologically-based corticothalamic NFT in a spherical geometry will enable more realistic modeling and analysis of experimental brain signals in future.

**Modular structure of functional brain networks for different human emotions from EEG data**

Richa Tripathi, Chakresh Kr. Singh, Dyutiman Mukhopadhyay, Shivakumar Jolad, Krishna Miyapuram

*Indian Institute of Technology, Gandhinagar*

We explore the topological structure of functional networks of emotional brain across various frequency bands of brain waves. We capture nine different emotional responses as outlined in Natya Shashtra in 14 healthy subjects. This was done using 128 electrode EEG recordings sampled at 250Hz by making them watch 3 minute long movie clips to evoke different emotions. These emotions were Karunaya, Bhibhatsa, Shringara, Veera, Hasya, Bhayanaka, Raudra, Adbhuta and Shanta. We analyse the signal in frequency domain and using Coherence measure, correlation matrices were obtained for each of the gamma, delta, theta, alpha and beta frequency bands. We extract a base network using these matrices for all the emotions for each participant, that is common across all emotions. Further, the contrast between actual emotion network, from the base network mapped onto the EEG cap was visualised. Robust communities were extracted using community detection algorithms for different frequency bands and emotions. This certainly unveils the cross talking between near and distant brain regions pertaining to different emotions and reveals emotional centres of the brain. Modular organization revealing functionally coactive brain regions correlates with variability in cognitive performance for different emotions.

**Multiple Kernel Learning Model for Relating Structural and Functional Connectivity in the Brain**

Sriniwas Govinda Surampudi[1], Shruti Naik[2], Bapi Raju Surampudi[3], Viktor K.Jirsa[4], Avinash Sharma[1], Dipanjan Roy[5]

*1. CVIT, IIIT-Hyderabad*
*2. Cognitive Science Lab, IIIT-Hyderabad*
*3. School of Computer and Information Sciences, University of Hyderabad*
*4. Aix Marseille Univ, Inserm, INS, Institut de Neurosciences des SystÃ¨mes, Marseille, France*
*5. CBDL, National Brain Research Centre, Gurgaon, Haryana*

A challenging problem in cognitive neuroscience is to relate the structural connectivity (SC) to the functional connectivity (FC) to better understand how large-scale network dynamics underlying human cognition emerges from the relatively fixed SC architecture. Recent modeling attempts point to the possibility of a single diffusion kernel giving a good estimate of the FC. We highlight the shortcomings of the single-scale diffusion kernel model and propose a multi-scale diffusion scheme. Our multi-scale model is formulated as a reaction-diffusion system giving rise to spatio-temporal patterns on a fixed topology. We hypothesize that the presence of regional multi-scale co-activations that initiate diffusion would be necessary to bridge the gap between structurally confined diffusion phenomenon and empirically observed FC and that these co-activations would be common across the cohort. We formulated a multiple kernel learning (MKL) scheme to estimate the latent parameters from training data. Our model is analytically tractable and complex enough to capture the details of the underlying biological phenomena. Our detailed empirical results demonstrate the validity of the proposed model on a larger dataset. The parameters learned by the MKL model lead to highly accurate predictions of subject-specific FCs from test datasets at a rate of 95\%, surpassing performance of the existing linear and non-linear models. We suggest that the learned latent parameters could be used as biomarkers for successfully classifying age-specific reorganization in the brain structure and function.

**Effect of reading expertise on letter representations in the brain**

Aakash Agrawal[1], K.V.S. Hari[2], S.P. Arun[3]

*1. Center for Bio-Systems Science and Engineering, Indian Institute of Science*
*2. Dept. of Electrical Communication Engineering, Indian Institute of Science*
*3. Center for Neuroscience, Indian Institute of Science*

Reading is a recent cultural invention that exploits the intrinsic recognition abilities of our visual system. Learning to read results in the formation of a specialized region in the visual cortex, the Visual Word Form Area (VWFA) that is activated more strongly by letters of a known script. However the nature of letter representations in VWFA and more generally the role of other visual areas in processing letter shapes is unknown. Here we set out to investigate these issues by exploiting the orthographic diversity of Indian languages. We selected two Southern Indian languages, Telugu and Malayalam which have entirely distinct scripts and relatively little overlap in populations. We identified two distinct groups of subjects that were both English-literate but with one group fluent in reading Telugu but not Malayalam, while the other group was fluent in reading Malayalam but not Telugu. Using fMRI, we measured the brain activity while the subjects viewed Telugu and Malayalam letters. Our main findings are as follows: (1) Each group of subject showed greater activity in VWFA and Wernicke's area for letters of their native script compared to the non-native script. In contrast, there was lower activity in the Lateral Occipital Cortex (LOC) and Early Visual Cortex (EVC) for native letters. This is a double dissociation thereby eliminating any confounds due to subject group or letter shapes. (2) The location of the VWFA peak was systematically different for Telugu and Malayalam letters; (3) VWFA voxel activations were correlated more strongly with Wernicke's area for native letters compared to non-native letters; (4) Frequent bigrams evoked weaker activity throughout the visual cortex; (5) VWFA activation correlated with language fluency across subjects. Taken together, our results suggest that VWFA is an intermediate stage of processing that integrates visual representations of letters with their auditory counterparts.

## Deciphering two-dimensional clustering from genetics for clinical subgrouping in Neuroimaging datasets

Abhishek Siroha, Cota Navin Gupta

*Dept of BSBE, IIT Guwahati, India*

Subgrouping algorithms for psychiatric disorders is still considered unexplored and challenging (G. Alturi et. al, Neuroimage clinical, 2013; C.N. Gupta et al, Frontiers in Psychiatry, Methods,Sept 2017). In this work, we deciphered two-dimensional clustering applied to gene expression data (M.B. Eisen et al, PNAS, 1998) to apply on Alzheimer's neuroimaging data for identifying clinical subgroups. The gene expression data of yeast during diauxic shift available in MATLAB clustergram function consisted of 614 genes (each row is a gene object) over 7 different time points (each column is a time object) (J.L. Derisi et al, Science, 1997). Euclidean distance for this 614*7 matrix is found in both column and row dimensions. Agglomerative clustering is then done on the distance squareform matrix for the column objects (i.e. time points) first and then on the row objects (i.e. genes) to achieve effective subgrouping. The entire subgrouped gene expression matrix is visualized using heat colormap. For this yeast gene dataset, we observed two sets of gene clusters showing varied expression over time. We are currently tuning this deciphered algorithm to structural magnetic resonance imaging data in Alzheimer's for clinical subgroup identification.

## Multimodal Analysis of Left Dorsolateral Prefrontal Cortex using Functional Proton Magnetic Resonance Spectroscopy and Functional Magnetic Resonance Imaging in Elderly Controls

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**Background and Objective of the study:** A combination of multiple brain imaging modalities has received much attention in studying the human brain. Neuroimaging techniques, particularly functional magnetic resonance imaging (fMRI), have provided much insight into the functional anatomy and neural networks of the brain. Functional proton magnetic resonance spectroscopy ($^{1}$H-fMRS) allows the in vivo measurement of dynamic changes in metabolites critically important for brain function. The strategy of combining fMRI and $^{1}$H-fMRS would enable the researchers to understand the biochemical interpretation of the BOLD signal. Neuroimaging and electrophysiological studies have consistently reported the involvement of Dorsolateral Prefrontal Cortex (DLPFC) in the processing of working memory (WM). WM deficits have been widely reported in patients with mild cognitive impairment (MCI) and Alzheimer's disease (AD). In this study, we tried to combine $^{1}$H-fMRS and fMRI to clarify the neurobiology of working memory in elderly healthy controls. This combinatorial approach would facilitate our understanding in establishing the relation between neuronal function and metabolite changes during the WM task.

**Methodology:** Thirteen healthy cognitively normal elderly subjects participated in this study. Magnetic Resonance Imaging and Spectroscopy studies were performed in a 3T GE MR750W scanner using a 24 channel coil. The anatomical T1 gradient weighted images and fMRI images were acquired using 3D Fast Spoiled Gradient Recalled Acquisition imaging and echo planar imaging pulse sequences respectively. Single voxel $^{1}$H-fMRS was performed using a point resolved spectroscopy sequence with a voxel size of 2×2×2 $cm^3$ positioned in the left DLPFC. For metabolite quantification LCModel with a simulated basis-set was used. Standard metabolites examined were N-acetylaspartate (NAA), myo-inositol, choline, creatine and glutamate-glutamine. For the fMRI and fMRS, N back WM task were administered. The fMRI analyses were performed using the

Statistical Parametric Mapping 12 (SPM12) in its native space. The volume of interest from the MRS experiment was used as a region of interest (ROI) in the fMRI native space analysis. MarsBaR toolbox of SPM was used to calculate the mean percent BOLD signal from the ROI. The relationship between metabolic changes and blood oxygen level dependent changes was analyzed using Pearson correlation.

**Results:** We observed a significant positive correlation between NAA and BOLD signal ($r = 0.682$, $p = 0.01$) during the performance of N back task in the left DPFC. No other metabolites were correlated with the BOLD activity in study group.

**Discussion:** This is the first study to correlate the changes in metabolites during the performance of WM task with the BOLD activity of fMRI in the left DLPFC of elderly controls. Our results reveal significant BOLD effects on the NAA metabolite, a marker of neuronal density. Therefore, the detection of the changes in NAA is essential for determination of the BOLD effects in the neuronal compartment. In future, the application of such multimodal imaging techniques might be useful in understanding the neuropathology of various psychiatric conditions and neurodegenerative diseases like MCI/AD.

**Happy emotional and prosocial words facilitate the sentence processing in Hindi and English: Evidences from early ERP components**

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Previous research has shown that displaying positive emotion and talking about helping sharing, and giving others makes optimistic impression by which one can establish friendship with others. We know very little about how our brain processes positive and negative emotional words, and pro-social and antisocial words embedded with verbs in sentential contexts. It has been found that our brain differentiates the valences of written and spoken emotion-words at either 200 ms or between 300 and 800 ms after onset of the stimulus (Kissler and Herbert, 2012). These neural time-courses are associated with the early posterior-negative (EPN: 200-300 ms) and the late positive-component (LPC: 300-600 ms) that reveal higher amplitudes for pleasant than for unpleasant words (Junghofer et al., 2001). We assume that these late processing of emotional words are due to the lack of contextual cues of emotional word processing. Emotion occurs in a context which characterises social interaction related to event (Stevanovic and Perakyla, 2014). We anticipate that our brain may process prosocial and positive emotional words much earlier, when verbal category of words including their time properties are manipulated to provide match-mismatch and grammatical-ungrammaticality in sentences. To investigate the early processing effect of emotional words, a semantic association was established between target emotional words and positive or negative verbs that occurred prior to happy or sad words in Hindi sentences. In second experiment, the target prosocial and antisocial words were embedded with grammatically correct and incorrect English sentences through manipulation of contextual cues of verbal properties. In both these experiments, Hindi-English bilingual participants performed a judgement task indicating (i) whether emotion-words matched or mismatched with verbs, and (ii) whether sentences were grammatically correct or incorrect. ERPs were time-locked to a target prosocial and emotion words in sentences (*e.g., ēka lŏṭarī jīt/ hāra ne kē kāraṇa śyāma khuśa/dukhī hai*). We saw modulation of early (P1) and late (P3) components in both these experiments irrespective of languages. Positive emotion-verbal words incongruence showed larger P1 amplitudes than positive-emotion verbal word congruence in the centro-parietal regions, whereas negative-verbal words incongruence elicited larger P1 amplitudes than negative-verbal congruence in the central regions. Similarly, prosocial words were processed much earlier i.e., P100 than antisocial words in centro-parietal, and pareito-occipital regions of brain. Our results indicate that emotional and prosocial contents in language are processed very rapidly and that the time-course of processing underlies the contextual cues of verbs or time properties of verbs in sentences. This suggests that happy emotional and prosocial words contribute to the survival of humans establishing their cooperation and group cohesion.

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**Large scale cortical waves predict future phase at localized sites at the single trial level**

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Predicting near future brain states--within fractions of a second--is important as a critical test of a brain signal's causal efficacy, for experimental manipulations of brain activity, and for brain-computer interface design. To enable such predictions, cortical activity must be regarded as a function of both space and time, and the two dimensions cannot be analyzed independently without loss of information. This principle is violated, for instance, by first averaging over time samples to then analyzing spatial maps of cortical activity. Moreover, even under identical task conditions, cortical activity varies over trials and times. Cross-trial or cross-time measures, such as averaged brain maps, ERPs, or Granger causality, wash out functionally relevant activity. To achieve near-future prediction of phase we use tensor decompositions of MEG data. Phase was estimated over the frequency range 2.0 to 16.0Hz using 2-cycle Morlet wavelets. Higher-order singular value decomposition enables characterization of this data as orthonormal bases, while maintaining its dimensional structure (here: samples x trials x frequencies x sensors x past-future activity). The model consists of a reduced-rank representation, to which a large-scale pattern of phase is input and the estimated future phase is output. The past and future time-series do not overlap, either in their phase representations or as raw signal. Prediction accuracy is assessed using previously unseen 50% of trials. At the best-predicted sensor site, the phase at the frequency and time of interest is predicted from the entire array of phase values two cycles previous. The circular variance of the error in predicted phase approaches a lower bound of ~0.3 to ~0.2, the exact value depending on the participant. For comparison, the lower bound of circular variance for prediction error of event-locked, cross-trial phase is ~0.2 to ~0.1; however, these latter are not based on predicting future signal from immediately past signal but require advance knowledge of the (uni-modal) trial-average in an event-related experiment. We note that long-time-series measures, such as phase coherence or Granger causality, predict relatively small amounts of the signal variance. An important research goal is to show that the global pattern of cortical phase is *sui generis* real, that it comprises a level of brain analysis that influences and emerges out of smaller scale dynamics. The present work is a step in this direction. At a practical level, the present technique is useful to experimental neuroscience, enabling computational anticipation of future brain activity for real-time modification of stimulus presentations. Brain-computer interface techniques based on signal phase have the potential for rapid response times, but are prone to phase-jitter. The present approach provides a method to reduce this jitter.

**Generic computations at the neural level can explain symmetry perception**

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Symmetry is a salient emergent attribute that influences a variety of fundamental perceptual processes like segmentation, recognition, and reconstruction. In spite of its importance in perception, we know very little about how symmetry is represented in neurons. To bridge this gap, we recorded neural responses from monkey inferior-temporal (IT) cortex to symmetric and asymmetric shapes created by joining two parts on either side of a stem. Shapes with identical parts were symmetric while others were asymmetric. We tested shapes oriented vertically and horizontally to characterize bilateral symmetry about both axes. We hypothesized that parts in a symmetric object interact non-linearly and cause the whole object response to deviate systematically from linear summation of part responses. We found that, across the population of recorded IT neurons, symmetric objects did neither evoke significantly stronger responses compared to asymmetric objects nor did they deviate from part response summation. However, the sole distinguishing characteristic of symmetric objects was that they were more distinct from each other compared to equivalent asymmetric objects. This distinctiveness can be explained as a straightforward consequence of part summation. Moreover, we also show evidence for distinctiveness driving symmetry judgements in human observers. Thus, the special status of symmetry in perception arises due to entirely generic computations at the neural level.

**Shape relations at multiple scale combine linearly**

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A classic finding in vision science is that we see the forest before we see the trees. When viewing diamonds arranged in a circle, humans can report the global shape (circle) faster than the local shape (diamonds). Although hierarchical stimuli are extensively used to study global/local processing, we understand little about their representation. Do shapes at global and local levels have same representation, do they interact or are they independent? To address these issues, we tested subjects on an oddball visual search task involving hierarchical stimuli where the target could differ from the distractors at either the global level, local level or both levels. This task paradigm helps to study global and local processing without explicitly asking the subject to do either of it. This allowed us to characterize how global and local shape differences combine in visual search. Our main findings are as follows. (1) Searches were easier when stimuli differed at the global compared to the local level, reflecting the global advantage effect; (2) Searches involving the same shape at both levels were easier than those involving different shapes at both levels, which explains why subjects are slower in processing incongruent stimuli in global/local tasks; (3)Search for any pair of hierarchical stimuli was explained accurately as a sum of global and local shape relations and cross-scale shape relations, all driven by a common shape representation; (4)Finally, model parameters varied systematically with the position, size and grouping status of local shapes. Taken together, our results show that hierarchical stimuli are organized in perception according to a surprisingly simple linear rule. This perceptual organization explains many previous observations about global/local processing.

**Measuring Causality using Compression-Complexity**

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Characterization of functional networks underlying perception, cognition, behavior and consciousness is becoming increasingly important in neuroscience. As a result, measures for estimating functional and effective connectivity, like Granger Causality (GC) (linear and non-linear), Transfer Entropy (TE), Dynamic Causal Modelling (DCM) are being used on acquired fMRI, EEG/MEG, ECoG data to determine connectivity between different brain regions. These measures range from being relatively model-free to model-based, with TE and DCM being on the two respective extremes and GC somewhere in the middle. While model-free approaches make the least assumptions on the data they are difficult to estimate for limited length. Moreover, they (TE and GC) have been shown to give spurious causalities for time series corrupted with noise, having low temporal resolution and non-synchronous measurements. Recently, we had proposed a novel measure of Causality based on Compression-Complexity (CCC) which is based on lossless data compression algorithms and is more generic than TE [1]. We had previously shown that our measure overcomes the limitations of TE and GC (linear) on simulated noisy and non-synchronous minimally coupled autoregressive processes. In this work, we compare the performance of CCC measure with non-linear GC on stochastic and chaotic processes. Also, for the first time, we show that CCC categorizes the causal influence into 'positive' and 'negative' causalities, giving additional insight into the 'kind' of information transfer between the given time series. We also evaluate the performance of CCC on measurements from a single-unit neuronal membrane potential recordings of squid giant axon in response to stimulus current.

A. Kathpalia and N. Nagaraj, "Causality Testing: A Data Compression Framework," arXiv:1710.04538 [physics.data-an], 2017.

**Whole brain resting state functional connectivity networks in Mild Cognitive Impairment and Alzheimer's disease**

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**Background:** Alzheimer's disease (AD) has been the most common form of dementia which characterized by a decline in cognitive and memory functions likely caused by aberrant neuronal circuitry. Although anomalies in the topological architecture of whole-brain connectivity have been found to be associated with Alzheimer's disease (AD); however the whole-brain functional networks of AD and its prodromal stage, mild cognitive impairment (MCI), remains largely unknown. Objective: The aim of the study was to investigate the whole brain functional networks of MCI, AD and controls. Methods: Patients diagnosed with MCI and AD in the Memory clinic at Sree Chitra Tirunal Institute for Medical Sciences and Technology (SCTIMST) were included in this study. Age and sex matched controls were recruited from the local population. All subjects were underwent a detailed clinical and neuropsychological evaluation along with MRI of brain. The study was approved by the Institutional Ethics Committee at SCTIMST. Written informed consent was obtained from each enrolled subject or his/her caregiver. Resting-state functional magnetic resonance imaging (rsfMRI) and 3D T1-weighted anatomical images were obtained from 20 MCI subjects, 21 AD patients, and 16 controls at 3T GE scanner. Whole brain functional connectivity patterns were assessed based on predefined template parcellated into 90 brain regions. The whole brain functional characteristics were compared between controls, MCI and AD patients by graph theoretical analysis. The association between functional connectivity strength and cognitive ability was evaluated in the MCI and AD group. Results: Compared with controls AD and MCI group demonstrated decreased whole brain connectivities at the threshold of $P<0.05$, FDR corrected. The most significantly affected regions in MCI include middle temporal gyrus, fusiform gyrus, anterior part of superior temporal gyrus and supramarginal gyryus. The AD patients exhibited decreased connections in precuneus, anterior and posterior middle temporal gyrus, inferior temporal gyrus, anterior fusiform gyrus, and supramarginal gyrus gyrus. Moreover, most affected connectivity was observed in interlobe connections such as temporal to frontal and temporo-parietal to basalganglia regions in AD patients. Post hoc comparisons of graph properties revealed that local clustering coefficient and local efficiency of posterior cingulate was significantly reduced in AD patients compared to controls. Moreover, a significant association was observed between functional connectivity strength and disease severity in AD patients. Conclusion: The present study suggest that functional integration in whole brain network was severely affected in AD and the better understanding of these will be critical to identify the neural basis of AD pathology.

**Prediction of autism spectral disorder by face processing by using high density EEG and pattern classifiers**

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Autism Spectral Disorder is a neurobiological disorder in which the affected individuals are deficit in social interaction, communication and social reciprocity. Dysfunctioning of face processing by our neural system is known to be a characteristic feature in case of ASD. Hence face processing can be selected as a task to distinguish the ASD children (non- typical) from the typical ones. Our objective was to correctly predict ASD and analyse the activity at all time points for both the groups. In the present study, high density EEG system has been used as a tool to record the face sensitive ERP for neutral and emotional faces. Five different types of images were shown in random order to both typical and non-typical children: Neutral, Happy, Fear, Cartoon and Tree. Machine learning algorithms were used to classify the two data sets. Two types of pattern classifiers were used: Class Wise Component Analysis (CPCA) and Support Vector Machine (SVM). Leave- one- out cross- validation and 10-fold cross validation was done on both the data sets. Both the classifiers could correctly predict ASD with relatively high accuracy. The accuracy was highest in case of cartoon. Highest activity was observed between 50 ms to 170 ms after the stimulus which was confirmed by plotting the scalp topoplots. In case of leave one subject out cross validation, higher percentage correct was observed for the typical kids than non-typical ones. Further analysis can be done to know the specific markers for ASD. Source Localization, used to localize the electrical activity of the brain, can tell us about the distinguished activity in brain for the two groups

**Effects of weak electric fields on neural activity**

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External stimulation techniques, such as transcranial Electrical Stimulation (tES), have been shown to modulate ongoing brain activity by applying low amplitude currents on the subject's head which. In computational models, the effects of external electric fields on neural systems strongly depend on the working point and the scale of the system. Here we present a systematic multi-scale study of the effects of external stimulation using a bottom-up modelling approach of (1) single neurons, (2) neural populations, and (3) human whole-brain models. Using an analytical solution of the effects of extracellular fields on a canonical spatially extended neuron, namely the ball-and-stick model, we present an extended point neuron model which captures the effect of a field on neural activity. Specifically, we show that the field effects can be incorporated into a point neuron model by an additional input current Using a mean-field approximation, we derive the firing rate dynamics of a recurrent neural network of excitatory and inhibitory cells. The model exhibits oscillations in the beta-range (15-30Hz) caused by an Hopf bifurcation due to delayed coupling of the excitatory and inhibitory population and in the delta-range (0.5-4Hz) range due to a slow adaptation current in the excitatory population. We study the resonant response properties of a network of coupled neurons, phase locking and frequency entrainment, and attractor switching caused by external stimulation. Furthermore, the phase relation between the input and the rate response of the population is presented depending on the current state of the system. Lastly, we study the effects of an electric field on the whole-brain dynamics using a network of interconnected brain areas. The connectivity matrix is derived from diffusion tensor imaging of long-range axonal fibers connecting different brain areas of the human brain. We model each brain area's local dynamics as two coupled populations of excitatory and inhibitory neurons and use excitatory coupling between each brain area. We parameterized our whole-brain model such that the simulated BOLD activity of the unperturbed system reproduces a very good fit to human resting state functional connectivity as well as functional connectivity dynamics. To model the effects of tES we apply an external electric field to a subset of nodes and observe large-scale effects such as propagation of the perturbation of a single node in rest of the brain and entrainment of activity across the whole cortical network.

## The Interplay of Senses: Sight and Smell

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The influence of a visual cue on a person's odour perception can help him or her to identify various substances around them faster and more accurately, as well as increase the intensity perceived while at the same time cause misidentification. We have designed experiments to study how and to what extent our visual cues influence our odour perception and wanted to try and understand the physiological basis behind it. To find this out, firstly we verified Weber's law for the differentiation between varying intensities of colour (pink) and calculated the Just Noticeable Difference (JND) and Weber's constant for it. The same was then done for the differentiation between varying intensities of strawberry odorant in colourless solutions. Using the obtained values of JND the extent to which the visual cues influenced the odour perception was studied. Participants were asked to arrange solutions with varying concentrations of colour and odorant in increasing order of perceived intensity where the solution with highest amount of colour had least amount of the strawberry odorant (and vice-versa). We found that an increase in concentration of pink colour by 5 JND did not compensate for the increase in perceived intensity by raising the concentration of odorant by 1 JND even in half the cases thus indicating that with the visual cue, the perceived intensity does not change significantly with an increase in colour. We then presented volunteers with solutions with varying intensities of pink colour and calculated the JND for the strawberry odorant and found that the JND decreased with the increase in amount of pink colour, implying an increase in sensitivity towards the strawberry odorant. Our results are in agreement with existing fMRI results where olfactory responses in the primary olfactory cortex (POC) as well as the orbitofrontal cortex (OFC) are shown to be modulated by the presence or absence of an external visual stimulus.

**Predicting visual percepts: MEG evidence**

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The human brain is a robust system taking its inputs from various sensory domains such as the visual, auditory and tactile domain for converting this information into internal knowledge. Various theories explain the neurological phenomenon of inferential perception. Predictive Coding is one of the most advanced and promising theory modeling perception based on internal knowledge. Here we analyzed the oscillatory mechanisms supporting Predictive coding. Importantly, we analyzed prediction outside the focus of attention, which was here determined by the task performed by the participants. To do so, we employed Magnetoencephalography (MEG), which provides reasonable temporal and spatial information of neuronal activity. Contextual visual information was provided by four (subsequent in time) gabor patches with intermediate CPD (cycles per degree) followed - after a fixed interval - by a target gabor whose CPD could be higher or lower compared to the gabor entrainers. Participants had to evaluate this dimension. In parallel, gabor orientation could vary along the different entrainers and target either randomly (Random condition) or gradually (Scaled condition), so that the gabor orientation could be predictable based in the latter case. Ten right handed (5 females, age range 18 - 29, mean: 23 , SD: 3.3) healthy participants (no visual deficit) took part in the study. Data were acquired using 306 channel MEG (Elekta, Neuromag) with sampling frequency of 1000 Hz. MEG signals were pre-processed with signal source separation procedure implemented in MaxFilter (Elekta ) to remove the movement artifacts and source generated noise. Further analyses were performed employing Fieldtrip. The time frequency estimation was performed using a hanning taper within a range of 1 to 35 Hz (1 Hz frequency resolution). We observed reduced theta power (4-8 Hz) for each entrainer in the Scaled compared to the Random condition. The effect increased in magnitude sequentially until the last entrainer and was evident time-locked to the target. We interpret this effect (the theta burst) as reflecting prediction error of the perceptual analysis to the stimulus. An additional alpha power effect (10 Hz) is observed in the frontal regions during the whole time window (entrainers plus target) showing increased power for the Scaled compared to the Random condition. The present findings highlight the adaptive response of the visual system that is extremely sensitive to the contextual information and

suggest a top-down modulation of the frontal alpha rhythms onto the perceptual visual activity.

**Task based Memory-Functional Magnetic Resonance Imaging for the evaluation of Memory Encoding & delayed Recall in Healthy Individuals and Patients with Mesial Temporal Lobe Epilepsy: A pilot Study**

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**Purpose:** To ascertain effectiveness of within-scanner encoding and recognition-memory paradigms for task-based memory fMRI in mesial temporal lobe epilepsy due to hippocampal sclerosis (MTLE-HS).

**Method**: Memory paradigms were designed for faces, word-pairs and abstract designs. The deep-encoding task was designed as a block design paradigm comprising of a total of 9 cycles run within a 1.5T MRI scanner. The recall session was performed after 1 hour within the scanner using an event related paradigm. Group analysis was done following post-processing of recognition memory performances, with 'correct-incorrect' responses applied as parametric modulators in Statistical Parametric Mapping version 8. The Laterality Index Toolbox with application of boot-strap method facilitated the estimation of laterality indices(LI).

**Results**: Fifteen subjects with drug-resistant MTLE-HS [10 patients of left-MTLE and 5 patients of right-MTLE] and 15 right handed age-matched healthy controls were recruited. For encoding paradigms the left MTLE-HS group revealed right lateralisation for word-pairs, designs and bilateral activation for faces. The right MTLE HS group demonstrated left lateralisation for word-pairs, designs and right lateralisation for faces over the regions of interest. Group analysis of delayed-recognition memory (cued-recall) BOLD signals acquired within scanner in the left MTLE-HS group demonstrated bilateral activations for faces (LI 0.081±0.19), right lateralization for word-pairs (-0.54±0.13) and designs (LI -0.21±0.07). The right MTLE-HS group demonstrated moderate left lateralization for faces (LI

0.25±0.13), strong left lateralization for word-pairs (LI of 0.51±0.18) and bilateral for designs (LI -0.035±0.16).

**Conclusion**: This is the first study validating intra-mural recall efficiency of material-specific memory paradigms equivalent to the widely-practised out-of scanner recall score based post-processing of encoded BOLD signals. Our results provide objective proof of hippocampal reserve in MTLE-HS.

**Patterns and surfaces combine linearly in visual search**

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Patterns on a surface remain recognizable even when the surface undergoes rigid, and even non-rigid transformations. To elucidate how this happens, we generated a set of images by systematically manipulating pattern shape and surface shape, and combining the resultant surfaces and patterns in a combinatorial fashion. In this design, congruent stimuli are those in which the surface and pattern undergo the same rigid or non-rigid transformation, and we predicted that these stimuli will be more similar in perception. To test this prediction we performed a visual search experiment on 12 human subjects. On each trial subjects viewed a search display with an oddball item among identical distractors, and were asked to indicate the location of the oddball. The time taken by subjects to find the oddball was taken as a measure of perceived similarity and its reciprocal was taken as a measure of dissimilarity. Our main finding is that searches for targets that differed in both pattern and surface from the distractors were accurately modelled as a sum of dissimilarities due to the pattern difference and the surface difference. This model explained all the explainable variance in the behavioural data, and accounted for both congruent and incongruent pairs of searches equally well. We conclude that pattern and surface information is separable and combine linearly in perception.

**EVD Assisted ICA Study of Optimally Thresholded Resting State fMRI Data**

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The resting state Functional Magnetic Resonance Imaging (rs-fMRI) is one of the important methods to obtain significant scientific findings explaining brain functions in terms of functional connectivity, i.e., the temporally correlated neuronal activations of spatially distributed brain regions that share information with each other. This connectivity can be identified by measuring the level of co-activation across rs-fMRI scans. State of the art neuroimaging techniques and analysis methods such as seed based cross-correlation analysis(SCCA), PCA, ICA and graph theory based network analysis have helped in the exploration of significant functional networks in the brain, enabling the in vivo study of functional connectivity across brains of multiple subjects. SCCA measures the similarity strength across brain voxels with a seed region-of-interest (ROI) whereas ICA factorises the low frequency BOLD signals into independent basis components and their projections to map the sources generating Low Frequency Fluctuations(LFF) across brain regions. Graph theory-based methods in other hand assume the brain to be a complex network and graphically represents the functional connectivity by a cluster of nodes and edges. However high dimensionality and complexity of the rs-fMRI data lead to the disadvantage of high computation time in these approaches. Here we propose a novel statistical and computationally efficient approach for data-driven functional connectivity analysis of rfMRI data using Eigenvalue Decomposition(EVD) assisted ICA. The proposed approach uses voxels with high BOLD values and nullifies the contribution of voxels accounting for pseudo activations. This results in huge spatial compression of the data without losing any significant information. This compression technique also accounts for fast Eigenvalue Decomposition with fewer principal components subsequently leading to faster algorithmic run times. Projecting the data matrix with reduced no of orthogonal components helps in expeditious ICA matrix factorisation with huge gain in memory and computation time. Experimental results confirm that the proposed approach is 5x faster, and can consistently find cleaner, noise-free and high quality functional networks compared to existing approaches, across data sets. Our claims are further supported by random initialisation and bootstrapping based reliability tests using ICASSO.

**Facilitating visual search using the wisdom of crowds**

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Group decisions are crucial for many animals who rely on the judgement of the group to take actions that essentially affect their survival. Group decision making is just as important for humans as it is for other social animals. In humans collective judgement has been found to be generally more accurate than individual decisions while performing complex cognitive tasks. An important aspect of collective decision making is aggregation of the independent contributions of the individuals into a collective output. Human groups most often employ the majority rule to come to a conclusion perhaps because of its ease in implementation. In our study we show that the weighted average of individual confidence ratings gives significantly more accurate judgement than the more commonly used majority voting pooling algorithm for a real-world visual search task and accuracy gradually increases as the number of subjects in a group increases. Assuming that neural information related to the decision making coming from multiple brains is more accurate than that from an individual brain, we should also be able to predict group decisions from the neural activity of individuals. In our case, we used machine learning algorithms to integrate information coming from EEG signals of 17 participants performing the visual search task independently. We evaluate how far the aggregation rules are successful in combining neural decision variables across multiple brains and observe that the average and weighted average rule give a better prediction about the presence or absence of the object from the neural decision variables.

**The effect of global signal regression on effective connectivity: A spectral DCM study**

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The use of global signal regression (GSR) in functional connectivity studies has been a topic of debate (Murphy & Fox, 2017). In the present study we assessed the effects of global signal regression (GSR) on effective connectivity, by using analyses that separate effective connectivity from hemodynamics and different sources of noise. Spectral DCM for resting state fMRI (Friston et al., 2014) is a method that allows such separation, by explicitly incorporating parameters representing state-, observation-, and sampling- noise and parameters representing effective connectivity and (neuro)vascular processes. Spectral DCM analyses of four longitudinal datasets (a total of 20 subjects) were combined to allow robust estimation of parameters within and across subjects. The resting state networks of interest were the default mode (DMN), salience and somatomotor network. Three research questions were formulated: (1) To what extent does GSR have an effect on effective connectivity at the group-level, (2) Does GSR have an influence on subject-level connectivity, and (3) Does GSR have a similar impact on different networks. Results showed that global signal regression did not have an important impact on effective connectivity, or any other estimated parameter. At the group-level, connectivity was in general smaller in magnitude (i.e., small shrinkage towards zero) after GSR, but no important differences (e.g., sign flips) were observed. Counter-intuitively, the parameter representing amplitude of neural fluctuations showed a higher percentage of change after GSR compared to the parameter representing global observation noise. The latter was observed for both the default mode and salience network, but not for the somatomotor network. GSR did not have an impact on hemispheric dominance of the DMN in 15 out of 17 subjects (88%), while 2 participants (12%) did not show evidence for lateralization after GSR (but no flips from left to right hemispheric dominance or vice versa were observed). However, hemispheric dominance was in general lower after GSR. GSR seemed to have a smaller impact on the salience network compared to other networks,

which might be related to the higher number of regions. In conclusion, we observed no important impact of GSR on effective connectivity within resting state networks.

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**The Emergence of visual pattern motion selectivity through Asymmetric lateral connectivity**

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Physiological studies indicate that the visual motion perception is carried out by the neurons in the motion pathway of primate brain, that consists of at least two stages: the primary visual cortex (V1) constitutes the first stage and the Middle temporal Area (MT) constitutes the second stage. In response to complex stimuli containing multiple components such as plaids (composed by additive combination of two or more gratings), neurons in V1 are responsive to the direction of the component motion (gratings) whereas the neurons in the MT are selective to the direction of the pattern motion (plaids). To inspect the computation of component and pattern motion selectivity, we proposed two-layer hierarchical feed forward neural network model, analogous to the neurons in the cortical areas V1 as well as MT. Each network layer consists of a two dimensional layer of rate coded neurons. Each neuron receives input through multiple sources: i) excitatory afferent connections from the square receptive field in the previous layer, ii) excitatory and inhibitory lateral connections from the neurons on the same layer within the specified radius. All the connections are adapted through biologically plausible asymmetric Hebbian rule in conjunction with postsynaptic divisive normalization. We hypothesize that the asymmetric lateral weight connections are the key to motion selectivity which is the novelty of this work. V1 cells were trained using a set of stimuli consisting of moving sinusoidal gratings, and that of MT cells were trained by the trained V1 cell responses to a range of possible plaids. The V1 and MT cell responses to the plaids on trained network were measured, and observed that: the component cells produced two activity blobs separated from one another whereas the pattern cells confined their response to single activity bubble. Interestingly, the two activity blobs produced in V1 in response to plaids is similar to the V1 responses corresponding to two grating components. This reveals the characteristic differences between component and pattern cells: the component cells are tuned to the direction of motion of the stimulus components whereas the pattern cells are tuned to the direction of motion of the whole pattern. The proposed two stage model neuron responses are consistent with the experimentally reported properties of V1 and MT cortical cells. To inspect the

individual neuron responses of the second layer, the pattern selectivity map was plotted. Stimulus motion is a temporal property that can be captured over sequence of frames. Unlike earlier proposed models that process moving stimulus explicitly with its time dimension, as a stack of frames, our model looks only at the current frame and knowledge about the past frames were stored in the network dynamics. Interneuron communication in the form of asymmetric lateral connections leads to network dynamics which captures the motion information in the moving visual stimuli. An earlier model of motion sensitivity in MT assumes explicit spatiotemporal filters, which is rather unnatural. The proposed approach does not require such assumptions and presents a more natural model of motion sensitivity in the brain.

**Effects of 40 Hz transcranial electrical stimulation of the parietal cortex on endogenous spatial attention**

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**Introduction:** The activity in the Posterior Parietal Cortex (PPC) is known to be associated with visuo-spatial attention and decision-making [1, 2]. Studies increasingly show that these cognitive processes can be modulated by stimulating the PPC using non-invasive brain stimulation techniques. The PPC also shows strong signatures of gamma-band (30-90 Hz) oscillations during attention tasks [3]. Here we apply transcranial Alternating Current stimulation (tACS) a neurostimulation technique that permits investigating the role of neural oscillations in cognitive behaviours. Specifically, we seek to study the effect of rhythmic stimulation of the PPC during a task involving the endogenous cueing of attention.

**Method and Task:** Behavioral data was collected from 16 participants as they performed a two-alternative detection/change-detection (2-ADC) task [4]. The task involved subjects to detect and localize the change in orientation of one of two gratings presented on a display, one in each visual hemifield. In 80% of trials contained, one of the 2 gratings changed in orientation ("change" trials) and in 20% no orientation change occurred ("catch" trials). Attention was cued with an endogenous, central cue and cue validity was 75% on change trials. Participants reported the location of change (left/right) or no change by pressing one of 3 buttons. Metrics of sensory and decisional components of attention, i.e. perceptual sensitivity and choice bias, were estimated from behavioral data using the m-ADC model [4]. The left or the right PPC were alternately stimulated at 40 Hz (effective current: 0.75 mA; duration 20 min) as the subject performed the task. Each participant also underwent a control sham stimulation and washout sessions, before and after the tACS stimulation session. tACS was applied to each hemisphere on alternate days, and the order of stimulation was counterbalanced across subjects.

**Results:** 40 Hz stimulation of the PPC produced qualitatively striking trends. Upon stimulation of the left PPC, perceptual sensitivity on invalidly cued trials -- trials in which the change happened at the grating opposite the cued location -- increased. On the other hand, upon stimulation of the right PPC, perceptual sensitivity on invalidly cued trials decreased (all comparisons relative to baseline performance in sham and washout sessions). The effects were strongest for stimuli in the visual hemifield ipsilateral to the stimulated hemisphere. Similarly, choice bias decreased upon stimulation of left PPC, and increased upon stimulation of the right PPC, on invalidly cued trials. Again, the effects were more pronounced in the ipsilateral visual hemifield. We are currently verifying these results quantitatively with appropriate statistical tests.

**Conclusions:** Our results suggest that 40 Hz tACS to the PPC modulates key sensory and decisional components of attention. The specificity of the stimulation effects to invalidly cued trials indicates that the stimulation primarily affected reorienting of attention toward the invalidly cued visual hemifield. The contrasting effects of stimulating the two hemispheres suggest dissociable roles for the left versus right parietal cortex in controlling attention, and requires further experiments to tease apart these distinct roles.

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**Understanding the Mesoscopic Organization of the Macaque Brain**

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In order to unravel how the brains of higher organisms, such as mammals, carry out cognitive and motor functions, it is crucial to understand the structural organization of the neurons at different levels of hierarchy. At a morphological level, the mammalian brain is compartmentalized into different regions (lobes, gyri, nuclei etc). Neurons of each of the brain regions seem to have extensive connections with neurons of one or more other brain regions. One approach to study this is to consider a mesoscopic network description of the brain, where the elementary units are brain regions which are connected to each other through bundles of nerve fibres. This has become possible to implement in brains of higher mammals, e.g., the macaque monkey, for which a large amount of data on different brain areas and their connectivity have been collated from experimental work using tracer studies, carried out over several decades. Considering brain regions as nodes and neuronal connections as links, we study the mesoscopic structure of the network of brain regions of macaque monkey. Using as our starting point a comprehensive study (Modha & Singh, 2010) that organized the data available from the CoCoMac database of macaque brain connectivity, we have reconstructed an unambiguous mesoscopic-level brain network. We use appropriate techniques to identify the different modules of brain network and interpret them in the light of correspondence between structure and function. We then compiled a database of the spatial properties of the brain regions, including their stereotactic coordinates and volumes, and analyzed the relationship between the network structure and the spatial configuration of the brain. We also used a community detection technique that filters out spatials effects and determined the extent to which the spatial arrangement of areas of the macaque brain influences its modular structure. We found that the macaque brain network exhibits highly modular structure, which is in accordance with known functional organization. Moreover, this holistic study of the brain network sheds some light on the functioning of the entire brain, as opposed to more focused studies on specific brain regions which helps us in characterizing many lesser understood regions in light of their modular memberships. This study strongly suggests that even though the connectivity is clearly affected by the spatial properties of the brain regions, the modular structure is more or less independent and hence its emergence must be seen as a more fundamental attribute.

**A model of memory consolidation in Hippocampus based on Reinforcement Learning**

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The hippocampus plays an important role in memory consolidation. Empirical studies have shown the dependence of hippocampal functions on the reward system. The role of neuromodulators in memory processing of hippocampus has not been resolved yet. Here we propose a model for the auto-associative memory processing of hippocampus by invoking the principles of reinforcement learning. We hypothesize that the EC estimates the value function (similar to striatum of basal ganglia) and the temporal value difference is related to the dopamine signals of the VTA neurons projecting to EC. This hypothesis is tested here by a model that performs retrieval task of the correct pattern (image) from its noisy version. The pathway from the sensory cortical areas to the HC and backward projections from HC to the same sensory areas is described as an autoencoder. Such a description is also in line with the idea that HC encodes stimulus-stimulus relationships in the cortex. The mapping of the proposed autoencoder to the relevant brain structures is as follows. The feedforward connections of the ventral pathway from primary visual cortex (V1) to the EC can be related to an encoder and the feedback connections can be related to a decoder. EC represents the highest abstract features generated by the encoder. Unlike the denoising autoencoder, this autoencoder is trained to generate the same noisy input. This input to the model consists of images of printed numerals 0-9 with varying levels of noise.The value is related to the noise level in the image: the value equals 1 for zero noise and decreases as a Gaussian function of the noise levels. In the model, the value is estimated from the center layer which denotes the EC. In this model, we further draw analogies between the functional pathways of the basal ganglia (the direct and indirect pathways) and the two parallel pathways of the HC (EC->DG->CA3->CA1->subiculum and EC->CA1->subiculum). We had earlier proposed that the dynamics of the basal ganglia pathways effectively perform stochastic hill-climbing over the value function represented by the striatonigral projections. This hill-climbing dynamics has been dubbed the Go-Explore-Nogo (GEN) policy. We now propose that similar

hill-climbing occurs in HC over the value function defined over the abstract features represented in EC. Hill-climbing over this value function is effectively equivalent to memory retrieval by the autoencoder. The proposed model of HC outperforms the iterative autoencoder in memory retrieval task. The model embodies a whole new theory of HC function. It proposes a concrete response to the question of what exactly is stored in the HC temporarily, and what is passed on to the long-term stores in the cortex. That response is: HC represents a value function defined over the features derived from the sensory cortex. Attractors of the hill-climbing dynamics over the value function are the stored memories.

**Hyperedge bundling: A practical solution to spurious interactions in MEG/EEG source connectivity analyses**

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Inter-areal functional connectivity (FC) and neuronal synchronization in particular, is thought to constitute a key systems-level mechanism for coordination neuronal processing and communication between brain regions. Evidence to support this hypothesis has been gained largely using invasive electrophysiological approaches. In humans, neuronal activity can be non-invasively recorded only with magneto- and electroencephalography (MEG/EEG), which have been used to assess FC networks with high temporal resolution and whole-scalp coverage. However, even in source-reconstructed MEG/EEG data, signal mixing, or "source leakage", is a significant confounder for FC analyses and network localization. Signal mixing leads to two distinct kinds of false-positive observations: artificial interactions (AI) caused directly by mixing and spurious interactions (SI) indirectly arising from the spread of signals from true interacting sources to nearby false loci. To date, several interaction metrics have been developed to solve the AI problem, but the SI problem has remained largely intractable in MEG/EEG all-to-all source connectivity studies. Here, we advance a novel approach for correcting SIs in FC analyses using source reconstructed MEG/EEG data. Our approach is to bundle observed FC connections into hyperedges by their mixing-wise adjacency. Using realistic simulations, we show here that bundling decreases the false positive rate while yielding good separability of true positives and little loss in the true positive rate. Hyperedge bundling thus significantly decreases graph noise by minimizing the false-positive to true-positive ratio. Finally, we demonstrate the advantage of edge bundling in the visualization of large-scale cortical networks with real MEG data. We propose that hypergraphs yielded by bundling represent well the set of true cortical interactions that are detectable and dissociable in MEG/EEG connectivity analysis.

**Machine learning based accurate classification of Schizophrenic and Healthy control Using Resting State fMRI features**

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In the last few years, there has been growing interest in the use of machine learning classifiers to classify healthy control and patient using fMRI data. In particular, for classification of Schizophrenic and healthy controls, using fMRI data has exhibited high precision and accuracy. Traditionally, task-based or behavioural response-based fMRI data was used for classification. The use of resting state networks (RSN), independent of any task-response criteria, for Schizophrenia classification is still a growing research topic.In this work, we have developed a computer aided automated classifier for Schizophrenic and Healthy Control classification using resting state fMRI Data. This is guided by the principle that Schizophrenic patients show varied RSN connectivity when compared to healthy controls. These RSNs contribute to the classification of Schizophrenic and compare its performance considering contributions of all networks using functional network connectivity and auto connectivity as the features. We evaluate the performance of Support Vector Machine and Neural Networks trained for classification on a set of schizophrenic and healthy control subjects. The performance of the two classifiers were discussed and Neural Network with 100 hidden layer neurons proved to be the most successful classifier with a maximum efficiency of 86.3% for the combined feature set and an average of 87.67%.An average accuracy of 87.67% is very promising in the field of Schizophrenic classification using Resting state fMRI data.

**Complex patterns of brain states in frontal and occipital cortical regions during wake-sleep-anesthesia stages in Rats.**

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The Electro Encephalography (EEG) data allows investigation of dynamical behaviour of complex brain-wave patterns exhibited in certain brain regions which may correspond to various dynamical brain states. We analyzed important functional cortical wave patterns in frontal and occipital areas in rat brain from the EEG data recorded during non-rapid eye movement (NREM), and rapid eye movement (REM) stages of sleep and anesthetic states, as well as during the transition of these states. The studies of these brain states in the motor (frontal area) and visual (occipital area) cortices are particularly important, because these cortical regions are primarily targeted for being associated with learning skills and memory consolidation respectively. We did baseline EEG recordings from the surgically implanted electrodes in healthy rats. The pre-processing of these data is done by decomposing the signal using ensemble empirical mode decomposition (EEMD) approach, by generating intrinsic mode functions (IMFs) where each IMF is representing a brain EEG rhythm with oscillations in a particular frequency range. The topological trends of brain waves (Delta, Theta, Alpha, Beta, Gamma), generated while being in a particular brain state and during transition among sleep-wake-anesthesia states, are investigated using Visibility graph algorithm, and found to manifest a number of distinct communities formed in their corresponding complex networks to EEG time series. This indicates the hierarchical organization of these neuron basis dynamical modules (most probably functional modules) to intricate various brain states in these cortical regions. The topological properties of these complex networks quantified by the parameters, such as clustering, connectivity and degree distribution have shown scale invariance nature with power law behaviour (fractal property) indicating ability to self-organize of neurons in these cortical regions. Neuron activities in a certain state can be characterized by energy spectral density of the EEG data during that states. The observation of significant variation in the complexity and power spectral density analysis of these brain waves could be the evidence of significant roles of each oscillation in that state and marks signatures for state transitions in the brain dynamics. The power spectral density plots during state transitions has showed emergence of particular brain oscillations characteristic of the subsequent state. Since power

spectral density is the energy spectral density per unit time, the observation of larger power spectral density in NREM-S1 and NREM-S2 as compared to other states show the emergence of more activities of the neurons in these states. Further, We have also found increased in activity of brain waves in the occipital region than frontal during each sleep stage with high power dominance in the NREM state. Brain topological properties exhibit multifractal nature because of various functionalities and emergence of non-linearities in the neuron dynamics. The multifractal analysis of the EEG time series data following Kantelhardt et. al. Multifractal detrended fluctuation analysis (MF-DFA), we observed the multifractal spectrum width of NREM stage is significantly higher than REM and WAKE stages characterizing highly complex interaction of the neurons in this state as compared to other states.

**Measuring Glu and GABA concentrations in the fronto-parietal cortex during visuospatial attention**

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Attention is central to cognition. In our daily life, we are continuously bombarded with tons of sensory information. Yet, we only attend to a small subset of information that is relevant for goal-directed behavior. Selective attention involves both the processing of task relevant information and suppressing task irrelevant (distracting) information. Therefore, a balance of excitation and inhibition in neural circuits processing attended information is likely to play a vital role in enabling selective attention. Two key brain metabolites -- an excitatory neurotransmitter, Glutamate (Glu), and an inhibitory neurotransmitter -- Gamma-Amino-Butyric Acid (GABA) -- are likely to be important for excitatory/inhibitory control during attention. Imbalances in their activity lead to excitatory-inhibitory (E/I) imbalance inside the brain and could lead to severe neurological disorders involving attention deficits including autism and schizophrenia. The fronto-parietal brain network is known to be consistently activated during spatial attention. However, the role of the key nodes of this network -- the dorsolateral prefrontal cortex (DLPFC) and posterior parietal cortex (PPC) -- in attention are unknown. Here, we seek to characterize and quantify the E/I balance in these key brain areas vis-a-vis their role in selective attention. We used proton magnetic resonance spectroscopy (1H-MRS) to measure the concentration of Glu and GABA at multimillimeter spatial resolution, using a state-of-the-art MEGA-PRESS sequence. Data were acquired with a 3 T MRI scanner with a 32-channel receive-only head coil (MAGNETOM Skyra; Siemens). Anatomical images were obtained with a high resolution T1-weighted pulse sequence to achieve internal landmarks for placement of the VOI followed by water suppression and auto shimming. The PFC, PPC and VC voxel was located on the middle frontal gyrus , near intraparietal sulcus and on the calcarine sulcus respectively. Then, MR spectra were acquired using MEGA-Press edited sequence in a Single voxel scan from three 3 *3 *3 cm3 VOIs positioned in the Visual Cortex, PFC and PPC with TE=68 ms and TR=3000 ms. The current experimental protocol consists of 4 blocks of rest and 4 blocks of an attention task (TA: 3:33 minutes per block). During the MRS scans human subjects either performed a selective visual attention task (2-alternative change detection task) or were resting with their eyes open (resting state), while we recorded their E/I ratios in the prefrontal, parietal and visual cortex. We seek to identify key differences in the E/I ratios in these different brain regions during task versus rest. The findings will be informing biophysically plausible models of neural mechanisms that mediate attention control in the human brain.

**Assessment of Engagement and its neurovascular correlates in a Situational Awareness Task: An EEG Informed fMRI approach**

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**Introduction:** Engagement reflects allocation of resources associated with decision making. Engagement Index is quantified as the percentage of beta power divided by percentage of alpha and theta power. The variation in these individual bands along with their BOLD correlates has been well studied but the interplay between alpha, beta and theta bands at the neurovascular level still remains unexplored. The goal of our study was to better understand the dependence of performance in a Situational Awareness Task on cognitive processes such as Engagement in terms of the effect of changing dynamics in EEG bands on the BOLD response.

**Aim of the study:** The study aimed to assess the Engagement and its neurovascular correlates in Situational Awareness task through EEG informed fMRI approach.

**Methods:** Seventeen healthy volunteers (Mean age= 24 years) with no known neurological disorder participated in this study. The designed SA task consists of slides, which require all the three levels of SA involvement such as perception, understanding and projection. The simultaneous EEG and fMRI data were acquired during the course of the SA task in 3T Siemens scanner. MR compatible Brain Amp EEG cap was used with 32 Ag/AgCl electrodes positioned according to the 10/20 system. EEG data was pre-processed for removing MRI related artifacts and EEG power spectral densities at the levels of alpha; beta and theta bands during SA task were measured. The information obtained from individual bands was used to calculate the Engagement Index (EI) values for SA tasks and baseline blocks for each volunteer. Further, the simultaneously acquired fMRI data was pre-processed and subjected to the General Linear model (GLM). The GLM model incorporated engagement index as one of regressor through parametric modulator to assess the correlation of fMRI BOLD information with the engagement index. For statistical analysis at the second level, desired contrasts pertaining to canonical, temporal and derivative terms were computed through one way analysis of variance (ANOVA).

**Results:** The contrast seeking correlation of engagement index with SA task found significant activations in Inferior Parietal Lobule (MNI coordinates: x=-54 y=-31 z=44), Cingulate gyrus (MNI coordinates: x=-6 y=20 z=17) and Para hippocampal Gyrus (MNI coordinates: x=12 y=-31 z=-4).The results were inferred using F-test with p<0.001. The obtained F-values for Inferior Parietal Lobule Region (Cluster Size=10 voxels), Cingulate Gyrus (Cluster Size=6 voxels), Para hippocampal Gyrus (Cluster Size=7 voxels) were 8.055, 7.115, 6.442 respectively.

**Conclusions:** The engagement during situational awareness task correlates with brain regions primarily known to be responsible for visual spatial attention, spatial perception and emotions. This collaborates with earlier findings which have shown that widespread system of sensory, parietal, and prefrontal areas are activated less than 50 to 80 ms from the visual observation of the individual which later initiates decision making processes from frontal and parietal regions onto sensory areas.

**Large-scale brain networks get entrained during processing of periodic auditory stimuli.**

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In the real world we are bombarded with a range of acoustic stimuli constituted of a spectrum of frequencies. Therefore, brain response to a pure tone could provide a window to understand how higher order harmonics are represented in the brain. Several electroencephalogram (EEG) studies have shown that stimulation by periodic auditory stimuli evokes a steady state response at the corresponding frequency, with 40Hz eliciting maximum response. Despite having enormous potential for clinical applications from measuring hearing threshold to characterizing the alteration of diseased state in Alzheimer's, the underlying network mechanisms are poorly understood. Present study exploits this paradigm to characterize the network mechanisms underlying binaural and monaural auditory stimulation. Subjects were presented with binaural and monaural stimuli. Pure tones at 1kHz frequency were presented at 40 cycles a second during the periodic stimulation period. We observed the enhancement of spectral power at individual participant and group level at 40 Hz in distributed scalp sensor locations. Maximum 40 Hz spectral power found in mastoid sensors and frontal central areas. Subsequently, we computed global coherence, an average of all of the pairwise coherences, to identify the presence of a large-scale brain network. Task-specific enhancement of global coherence specifically at 40 Hz indicates the recruitment of a large-scale neuronal network in monaural and binaural conditions. Hemispheric analysis revealed the ipsilateral dominance in the processing of monaural stimuli. Subsequently, measurement of pairwise imaginary coherence to detect sub-networks were carried out. Statistical testing of interaction among channel pairs was done using non-parametric tests. Bilateral long range interactions involving centro-frontal and temporal sensors and parietooccipital sensors were significant. These interactions were ipsilateral dominant in monaural conditions. To identify the causal influence in all significantly interacting channel pair we employed Granger causality (GC) analysis. In both monaural and binaural conditions, GC revealed the influence of right temporal region to the frontal areas. In conclusion, we establish the presence of large-scale effective networks encompassing bilateral auditory and frontal areas that get entrained during the processing of 40 Hz auditory stimuli.

**Age dependent causality change in Cortical Hubs over lifespan**

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Gradual decline of cognitive functions with aging is associated with decreased functional connectivity in Resting State Network (RSN) hubs [1]. Tracking changes in topological properties of these hubs can provide insights on information segregation and integration of Neurocognitive networks at different age [2, 3]. Here we inspect structure-function correlation in various regions and observe changes in their topological metrics over age. We also investigate directional connectivity of hubs to find out their causal influences over different age groups. We hypothesized that we would find major differences in modularity and causality measures in hubs with increasing age. The main objective of this study was to assess the relationship between mPFC-PCU (Precuneus) DMN connectivity using pairwise functional correlation (FC) between region wise BOLD time series signals. Subsequently, to chart systematically the variability of SC-FC correlation across subjects using multivariate analysis with varied age (young, middle aged and elderly cohorts). The specific hypotheses tested were: (1) mPFC-PCU connectivity will be reduced in aging; (2) regions correlating with mPFC-PCU coupling strength will be located in areas of high age-related vulnerability; (3) Change in causality statistics of these regions should be able to explain the ’direction’ of damage in SC-FC coupling with aging. Resting-state fMRI and DTI (Diffusion Tensor Imaging) scans were acquired from 50 healthy participants (age range:18-81, mean: 41.5±18.44yr). and structural (SC) as well as functional (FC) connectivity matrices were calculated from preprocessed data. We investigated SC-FC (structural-functional) correlation using Pearson Correlation for each pair of ROIs. We found high correlation for regions which are part of 1. DMN-PCC/MPFC/IPC 2. Salience Network-dACC/insula and 3. Central Executive Network-dlPFC. Applying Partial least square (PLS) regression with age revealed decreased SC-FC connectivity in DMN as well as decreased modularity (cingulate cortex, parietal cortex, occipital cortex) with aging. Moreover, systematic reorganization of FC was observed within distant module pairwise correlations suggesting age dependent variability of functional brain networks. We then explored causal influences between each pair of ROIs using Granger Causality Index. PCC seemed to influence all other regions and had highest granger causality index followed by other default mode hub regions. PCC also remained the least affected hub with respect to age. The pattern of causal relationships of hubs changed significantly with aging. Disrupted causality dynamics of important hubs (mPFC, MTL) can ex- plain their gradually vanishing roles in function integration with aging. Change in causality of hubs might prove in future an important biomarker for various neurodegenerative diseases. This study, to best of our knowledge so far, is the first multivariate study investigating change in causality dynamics of functional hubs to explain SC-FC changes across life-span

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**Neural mechanisms of inter-group and inter-trial variability in cross-modal speech perception**

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Perception of speech inextricably involves multisensory integration. Research directed towards understanding the neuronal mechanism of speech perception predominantly employ the McGurk effect. During McGurk effect participants percieve illusory speech sound when presented with incongruent audio-visual(AV) stimuli. Although, a significant proportion of the participants rarely percieve the illusion. Notably, the exisiting studies in the field primarily accentuate the correlation between subjective behavior and cortical activations to demonstrate the underlying mechanism. However, this approach does not provide direct evidence of the mechanism. In the present study, employing biophysically realistic neuronal model we explain our empirical findings on the large scale functional brain network underlying speech perception. Importantly, we also show objective difference in the mechanism of AV speech processing between frequent and rare perceivers of McGurk effect. Combined together, we present a comprehensive picture of the neuronal mechanism underlying multisensory speech perception. EEG data was collected from 35 healthy volunteers who signed informed consents, approved by the Institutional Human Ethics Committee of National Brain Research Centre, India. The paticipants reported their percept while watching a set of incongruent and congruent AV stimuli using a set of three keys. Based on the behavioral responses, the participants were categorised as frequent and rare percievers of the McGurk illusion. We further computed global coherence and employed cluster based permutation tests to study the dynamics of the cortical network following multisensory perception. Furthermore for generating neuronal model, a network of excitatory and inhibitory Hindmarsh-Rose neurons were used to represent a cortical area. Different time constants were used in the network to distinguish between auditory, visual and multisensory areas. Subsequently, coherence spectras were computed between these areas with varying coupling strengths between these areas. Our empirical results for frequent percievers, showed an enhanced gamma band coherence accompanied by decreased alpha band coherence following multisensory perception. However, for rare percievers, multisensory perception was charecterised only with a decreased alpha coherence. Interestingly, our neuronal model exhibited a coherence pattern similar to frequent percievers when the coupling strength between the auditory and visual nodes was increased. Intuitively, besides the aforementioned enhanced coupling, an increase in the coupling between the auditory and the multisensory node simulated the coherence pattern of the rare percievers. Together, we explain our empirical results in the light of dynamical neuronal model therby establishing the mechanism that underlie multisensory speech perception.

**Functional (re)organization of brain networks during visual perception and visually guided action**

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Dual stream hypothesis is a pre-eminent theoretical approach to conceptualize visuo-motor information processing. Subtle variations of the model exist often leading to fundamentally divergent explanations of underlying neural mechanisms. For example, the Mishkin-Ungerlieder (MU) model suggests that the input information decides the neural pathway for processing. Position related information ('where') takes the dorsal stream c omprising MT/V5and parietal cortex whereas finer feature processing ('what') comprising color, face, etc. takes the ventral stream involving V4 and inferior temporal areas. Concomitantly, the Milner-Goodale (MG) model suggests that the task goal decides the processing pathway, with dorsal stream areas needed for visual (sensory) guidance of action that doesn't involve active perceptual processing whereas the ventral stream is recruited for perceptual object processing. No single study has evaluated the viability of each model in an overarching experimental design. Furthermore are the models subject to neuroplastic changes is an open question. We addressed these issues in an fMRI experiment involving 20 right-handed human volunteers (20-34 years, 12 females). Participants were scanned with TR=2 s TE= 35ms, flip angle =90 while each of them was performing 3 visual perception tasks and 3 visuo-motor action tasks inside a 3T MRI scanner. For both categories, 2 tasks were designed to involve "what" (color, face) processing and 1 task required processing of "where" (position) information. The fMRI scans were repeated after seven days of the practice session outside the scanner to explore the neuroplastic changes. In all perception tasks, bilateral ventral stream areas are activated, whereas all action tasks show prominent activations in bilateral primary visual cortices, ventral and dorsal stream regions. Unlike color and face perception task, the position perception task shows additional activation in bilateral dorsal stream and pre-motor cortex. Activation in position perception task cannot be sufficiently explained by one model only. In all perception tasks, but not in any of the response tasks, there is extensive area of deactivation involving primarily medial dorsal stream areas but also primary sensory and ventral stream area. Analysis of reaction times established the positive effect of practice. With practice, in general, there is decrease in the extent of both activated and deactivated regions. Effective connectivity analysis (Multivariate Granger Causality ) revealed the direct causal connection between the ventral and dorsal stream to be most consistent among different task conditions.

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**Microstructural anatomical differences between bilinguals and monolinguals**

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DTI is an established method to study cerebral white-matter microstructure. Two popular measures of DTI are fractional anisotropy (FA) and mean diffusivity (MD) which was reported to differ for bilingual and monolingual speakers. Here, our aim was to compare FA, radial diffusivity (RD) and axial diffusivity (AD)in bilinguals and monolinguals. Mean FA-values for bilinguals were lower than monolinguals in the anterior thalamic radiation, right inferior fronto-occipital fasiculus and inferior longitudinal fasciculus (ILF) and MD-values for bilinguals were higher in forceps minor and bilateral superior longitudinal fasciculus (SLF). Mean AD and RD were higher for bilinguals in the forceps minor and right SLF. We reasoned that higher values in concomitant areas reflect bilingual experience and find support from a positive correlation between RD-values and L2 proficiency. We contend that bilingual experience generates neuroplasticity specifically in the right SLF due to more demands on cognitive control.

## Spatiotemporal boundaries of the P300 complex across multiple sensory modalities

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The P300 complex is associated with cognitive processes such as attention and memory. An oddball paradigm in which, a deviant stimulus is infrequently presented amidst a sequence of standard repetitive stimuli to a human volunteer typically exhibits a positive peak in the event related potential (ERP) recording via electroencephalogram (EEG) at a latency of around 300 ms from the onset of the stimulus. Significance of P300 ranges from being a marker of neurological disorders to BCI applications. Various source localization techniques have been implemented over the years to localize the underlying neural generators of the P300 suggesting involvement of frontal temporal and parietal regions. Although, different paradigms and sensory modalities (e.g., visual, auditory, somatosensory) have been used, the spatiotemporal boundaries of the cortical generators remains poorly understood. Do the P300 complex for different sensory modalities have common cortical sources or is it generated by areas responsible for the processing of corresponding sensory modality?

We address these questions using electroencephalogram (EEG) recordings of 12 human volunteers of age between 20 and 30, while presenting multiple combinations of sensory modalities i.e. auditory, visual and audio-visual. The auditory condition consists of two separate tones of different frequencies one of which is the high frequency deviant stimulus (14% of total trials) and the other is the low frequency tone (86% of total trials). Analogously, the visual stimuli consist of two class of trials, one of which was a red triangle as the deviant stimulus (14% of total trials) and the other, a blue square, as the standard stimulus (86% of total trials). Similarly, audio-visual (AV) stimuli consisted of the deviant videos (14% of total trials) that consisted of high frequency tone and a red triangle among a set of standard repetitive videos that consisted of lower frequency tone and blue square (86% of total trials). The duration of the stimuli was 200 msec long with an ISI of 400 msec. The stimuli were presented via Presentation (Neurobehavioral Systems Inc.) software and 64 channel EEG data was recorded at a sampling frequency of 1 KHz. Additionally, a 3D coordinate tracking system, Polhemus was used to estimate respective electrode positions for co-registration with individual participant’s structural MRI data collected using a 3T Philips Achieva scanner.

Post epoching and preprocessing EEG raw data, presence of P300 complex was verified using t-test between deviant and standard trials. 2 peaks of the P300 complex in visual condition and 3 peaks in the audio and AV conditions, were identified. Moreover, the onset of the P300 complex in the AV condition was observed to be earlier compared to audio and visual conditions. Larger amplitude of visual P300 was detected, while similar amplitudes were noted for audio and AV conditions. Sources of each peak were computed using algorithms: eLORETA and LCMV, for each subject, by co-registration of the Polhemus data and their respective T1 MRI image. The source intensities were normalized and visualized on an MNI template. The cortical locations underlying detection by two separate localization methods, eLORETA and LCMV were assumed to be more probable sources underlying the P300 response. Left and right middle temporal gyrus and areas in frontal lobe were found to be the common sources of P300 in all the conditions. Although, contrasting from audio condition, activity in the inferior parietal lobule and other parts of the parietal cortex was observed in visual and AV conditions. The differences and similarities of cortical locations underlying P300 complex can give us more insight into the networks concerning unisensory and multisensory processing.

**Radiological Correlates of White Matter Integrity changes of Corpus Callosum in High-Grade Glioma using Diffusion Tensor Imaging Study**

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Corpus Callosum (CC) the largest fibre bundle of the human brain connects the two hemispheres significantly and thus plays the major role in synchronized functioning by both halves of the brain. The lesions or the neurodegenerative changes in corpus callosum resulting in atrophy will have the significant changes in cognitive capabilities of an individual. Gliomas, the major type of brain tumours is assessed in the study, the changes in diffusion properties of the corpus callosum are analysed. Here we aim to investigate the changes in the corpus callosum using white matter diffusivity indices in High-Grade Glioma (HGG-Type IV), 8 patients and 8 healthy individuals (controls). Corpus callosum volume, corpus callosum fiber tract output to the whole brain and the various diffusion measures such as fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), radial diffusivity (RD), lattice Index (LI) and geometrical indices ($C_l$, $C_p$, $C_s$) were calculated from diffusion tensor imaging (DTI) using FMRIB Software Library (FSL). Our study has revealed that the axial diffusivity (AD) and mean diffusivity (MD) has been significantly increased, ($p=0.03$ and $p= 0.02$) respectively in the corpus callosum of glioma patients while fractional anisotropy (FA) has shown no significant changes ($p>0.05$). Further, we aim to grade the barycentric parametrization of the anisotropy between linear, planar or spherical anisotropy. The fiber tract analysis showed the significant reduction of fiber tract count ($p=2.48682\text{X}10^{-7}$) and significant decrease in corpus callosum volume ($p=4.88\text{X}10^{-5}$) in glioma patients when compared to healthy individuals. We did not notice significant changes in linear, planar and spherical anisotropy in corpus callosum for glioma and healthy individuals. The white matter diffusivity changes play a crucial role in determining healthy functioning or neurodegeneration in HGG, the results support the proposition of association between alteration of interhemispheric connections (CC) changes in HGG, and the extended study in future may help to diagnose the glioma grades using CC measures, in particular, the axial diffusivity, volume changes, and the fiber tract measures to be the identifiers.

**Keywords:** Corpus callosum, High-Grade Glioma, Geometrical Indices, Lattice Index, Fractional Anisotropy, Axial Diffusivity, FSL.

**Temporal lobe epilepsy as a network level disease: analysing language networks in left and right TLE patients by resting state fMRI connectivity analysis.**

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**Aim:** To investigate differences in resting state functional connectivity (rs-FC) between healthy controls, left temporal lobe epilepsy (TLE) and right temporal lobe epilepsy patients. We aim to correlate the z-score obtained from rs-FC analysis with task-fMRI laterality index (LI).

**Methods:** 15 healthy controls, 8 left temporal lobe epilepsy and 7 right temporal lobe epilepsy patients were prospectively evaluated using conventional rs-fMRI language-task-fMRI. The imaging was done in a 3T GE scanner (Discovery MR750wTM) using a 32 channel head coil. Task-fMRI was done with the aid of visual verb paradigm. Seven regions of interests (ROIs) from both left and right hemispheres of Broca's area (Brodmann Area 47, 44 and 45), Brodmann area 6 & 9, and Wernicke's area (Brodmann Area 21, 22 ) were obtained using Marsbar toolbox were used for rs-FC and task-based LI analysis. Graph theoretical analyses were done for all subjects and were analyzed separately. ROI to ROI rs-FC was done using Conn connectivity toolbox. Functional connectivity correlation matrix of all respective language regions were Fisher transformed to get z scores. Similarly LI toolbox was used to extract the LI values from language based-task fMRI. Z scores obtained from 14 ROIs were subjected to F test. z scores obtained from Brocas areas after rs-fMRI connectivity analysis of healthy control, left TLE and right TLE were correlated with the LI obtained from task-fMRI obtained from the same.

**Results:** The F statistics ($p<0.05$, FDR corrected) shows group difference in connectivity between seed ROI and all other target ROIs. According to F statistics, left TLE and right TLE patients exhibited reduced rs-FC when compared to healthy controls. Within the patient group, right TLE patients exhibited most reduced connectivity among language areas. Among the analysed connectivity,

for left TLE group, ROIs like Right Brodmann area 21, 44, 45, 47 and left Brodmann area 6 showed increased connection when compared with right TLE patients. Whereas for right TLE patients, ROIs like left Brodmann area 21, 22, 44, 45, 47 and right Brodmann area 6 showed increased connection. Z score of rs-FC analysis on Brocas area when correlated with the LI of Broca's, Wernicke's and Brodmann area 9 showed a Pearson correlation value of 0.527 for healthy controls, 0.634 for left TLE and 0.718 for right TLE patients.

**Conclusion:** There is reduced strength of rs-FC in the left side of left TLE patients and right side of the right TLE patients. It might be the reason for strengthened rs-FC at the contralateral side. The correlation coefficient of laterality index obtained from Broca's, Wernicke's and Brodmann area 9 with the z score obtained from Broca's area showed a moderate correlation for healthy controls, and a good correlation for left and right TLE patients.

## The Dance of Mirror Neurons

The choreography is inspired by the mirror neurons and our starting point was mirroring a partner's body movement. We have explored word association game and sub conscious habits we learn from friends or family as a way to work with the subject as well. Real mirrors were used for further experiment and the performance is mostly improvised live.

Choreography: Swati Mohan
Dance collaborators: Rakesh, Zoya Duggal, Nyanada Patil, Deepak Bhatia and Amit
Sound design and Singer: Sukanya Chattopadhyay
Original Composition integrated in sound design: Bye Bye Butterfly by Pauline Oliveros
Neuroscience Consultancy: Arpan Banerjee from National Brain Research Centre, Gurgaon
Video Source: NBRC
Wesbite: www.danzaperformingarts.in

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