Functional connectivity studies using functional magnetic resonance imaging (fMRI) have reliably observed both resting state activity and task-related activity in functionally connected networks. However, characterization of the time-course of activity within these networks has been limited by the time-scale of the fMRI BOLD response. Multimodal imaging methods are capable of measuring those time-courses by combining the spatial resolution of fMRI with the high temporal resolution of EEG, MEG, and Electrocorticography (ECoG). One approach involves simultaneous EEG and fMRI recordings, such that the time-course of oscillatory activity in an EEG component can be related to the time-course of activity within a given fMRI network. Another approach involves recording fMRI and MEG data in separate sessions from the same individuals. The MEG data can be localized to cortical regions via a variety of algorithms such as beamformers and minimum norm estimates. A third approach involves the sequential acquisition of fMRI and direct electrophysiological recordings from the cortical surface (ECoG) in patients with epilepsy. Functional connectivity analyses can then be performed separately on the fMRI data and the EEG/MEG/ECoG data, and overlap between different measures can be assessed through various statistical frameworks. Converging results from these diverse methods describe spatial redundancies between fMRI and MEG/EEG data. They also describe how oscillations at various frequencies form functional networks across brain regions. As EEG/MEG/ECoG data are real-time measures of neural activity, these methods allow us to describe with high resolution the time-course of activity within the networks identified via fMRI.

Learning Objectives: Having attended to this symposium, participants will be able to:
1. Understand the importance of using brain networks as a framework for examining brain function;
2. Understand how multimodal imaging can describe brain activity with high spatial and temporal resolution; and
3. Understand how different frequencies of oscillatory signals in different brain regions can underlie a given network identified in the BOLD signal.

Spatial Correspondence Between Networks of Oscillatory Activity Identified in MEG Data and the Dorsal Attention and Default Mode Networks Identified in fMRI Data

Combining the spatial resolution of fMRI with the temporal resolution of EEG or MEG data recorded from the same individuals under the same experimental conditions allows precise descriptions of both the spatial pattern of a functional brain network and the time-course of its activity. Computational algorithms such as beamformers can localize the cortical generators of MEG data with sufficient detail that the spatial patterns of MEG results can be compared to the spatial patterns of fMRI networks. An effective approach to such comparisons involves using fMRI networks as spatial predictors onto which beamformed MEG data can be regressed, using Constrained Principal Component Analysis (CPCA). In this approach, CPCA is first used to identify functional networks in the fMRI data which display task-related changes in activity. In a variety of paradigms, fmri-CPCA
Beamformed MEG data then serve as the dependent variables in a second CPCA analysis. Images of fMRI networks serve as spatial predictors, whereas timing information for the task performed during MEG data collection serves as a set of temporal predictors. The networks of oscillatory signals revealed by this approach will be discussed.

**Investigating the Spatial-Temporal Dynamics of Functional Networks with Simultaneous EEG-fMRI**

Rene Scheeringa, *Donders Institute for Brain, Cognition and Behaviour, Centre for Cognitive Neuroimaging, Nijmegen, Netherlands*

Simultaneously recorded EEG and fMRI offers the possibility to study the relationship between changes in EEG power and distributed functional networks measured by fMRI. There have been different approaches taken to investigate this relation. In this talk I will discuss and summarize four distinctions in the approaches currently taken to examine the relationship between EEG spectral perturbations and BOLD. The choices made with respect to these four aspects of simultaneous EEG-fMRI studies are important for the inferences that can be made on the results.

One distinction that can be made between the approaches in different studies is whether they focus on studying the relation between task evoked BOLD and EEG power effects or resting state. A second difference between studies is whether the EEG-power fluctuations are studied at scalp level or in source space via beamformer techniques or other blind source separation methods like independent component analysis. The third important distinction is whether broad-band frequency specific effects are studied, or whether the relation between single frequency bands and fMRI defined functional networks is studied. Finally, the fourth difference is between studies that investigate the relation between EEG power changes and fMRI activity or studies that focus on how connectivity between regions measured by fMRI is modulated by EEG power changes. These consequences these choices have with respect to interpretation, and other advantages and disadvantages of the different approaches will be discussed in the context of our own work and the work of others.

**Investigating the Electrophysiological Origin of Brain Networks Using Magnetoencephalography**

Matthew Brookes, *Sir Peter Mansfield Magnetic Resonance Centre, School of Physics and Astronomy, University of Nottingham, Nottingham, United Kingdom*

In recent years the study of resting state brain networks (RSNs) has become an important area of neuroimaging. Connectivity between spatially separate but functionally related regions is thought to be an integral part of information processing in the brain. More importantly, abnormalities in network connectivity are thought to underlie a number of pathological conditions including ADHD and schizophrenia. Gaining insight into network connectivity is therefore a key goal for current neuroimaging research.

The majority of studies in this area employ fMRI to measure temporal correlation between BOLD signals. However, BOLD is an indirect measure related to haemodynamics with poor temporal resolution, and cannot be used to elucidate the rich electrophysiological signals that help mediate connectivity in the healthy cortex. This talk will review a number of different methodologies that can be used to characterise electrodynamic brain network connectivity independently using MEG data. The use of mathematical techniques including seed based correlation, independent component analysis and multivariate analysis within a source localised (beamformer) framework will be discussed. Results of these analyses yield electrophysiological networks whose spatial signatures exhibit significant similarity to
networks derived independently using fMRI. The work presented will confirm the neural basis of haemodynamic networks, and demonstrate the potential of MEG as a tool for understanding the mechanisms that underlie network formation and the nature of connectivity that binds network nodes.

**A Frequency-Specific Mechanism that Links Human Brain Networks During Task Performance**

Maurizio Corbetta, Departments of Neurology, Radiology, Anatomy & Neurobiology, Washington University School of Medicine, St. Louis, Missouri, USA

A fundamental issue in neuroscience is how different regions of the brain interact to successfully implement a cognitive task. Even the simplest behavior requires that multiple neural processes come on-line simultaneously without interference from uninvolved neural populations. Functional brain imaging studies have identified networks of broadly distributed brain regions that are consistently recruited during task performance; however interactions between regions belonging to the same or different networks are poorly understood. Here, we first use functional MRI to localize in human subjects different brain networks. Then, we directly record cortical physiology during a spatial attention task to study network dynamics. We show that distinct frontoparietal networks (dorsal and ventral attention) become phase synchronized in the low frequency range (delta, theta) during the same task epochs in which they are recruited in fMRI, supporting the idea that dynamic patterns of neuronal coherence support long-distance interactions between brain regions as a task unfolds. Furthermore, different attention processes (holding vs. shifting attention) are associated with synchrony at different frequencies, possibly minimizing unnecessary cross talk between separate neuronal processes. Finally, simultaneous recordings from regions in a task-irrelevant (default) network show weaker synchronization and more variable phase relationships than in task-relevant regions/networks. These results demonstrate a frequency-specific neural mechanism for dynamically linking distributed human brain networks during task performance.

**Session Topic(s):**
Disorders of the Nervous System
Higher cognitive functions
Imaging Methods
Modeling and Analysis Methods