The Electrophysiological Basis of Resting State Networks

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Introduction: In recent years, a great deal of fMRI literature has focussed on investigating the structure and function of brain networks. Many such studies have employed 'resting state' fMRI recordings to delineate a set of networks, some associated with simple sensory processing (visual, auditory, motor etc.) and some associated with higher-level processes (e.g., the dorsal attention network, default mode network and salience network). These networks appear to be integral to human brain function; further, abnormal network connectivity is thought to be responsible for pathological conditions (e.g., schizophrenia). Gaining a complete understanding of such phenomena therefore represents a key goal for neuroimaging. BOLD fMRI delineates networks with unparalleled spatial resolution. However, it remains an indirect measure of 'brain activity' and neither the most rapid temporal dynamics nor the electrophysiological basis of network function can be assessed using fMRI alone. Magnetoencephaloography (MEG) is a non-invasive technique that allows a more direct assessment of electrical brain function by assessing magnetic fields associated with synchronous current flow in pyramidal neurons in the cortex. Previous work[e.g. 1] has begun to highlight the ability of MEG to measure functional connectivity between network nodes, and such measures have also shown similarity with fMRI[2,3]. In this abstract we report the results of a resting state MEG study that independently identifies multiple brain networks in MEG data. We compare these electrophysiological networks directly to previously published work in fMRI[4] and show significant similarity between modalities.

Methods: Ten healthy participants took part in the experiment. Subjects were asked to lie in the MEG scanner whilst 300s of resting state data were acquired using a 275 channel CTF MEG system (sample rate 600Hz) in 3rd order gradiometer configuration. Co-registration of MEG data to 3T anatomical MRI (MPRAGE, 1mm^3) was achieved using head digitisation and surface matching.

Data were filtered into frequency bands of interest and projected from sensor space to source space using a beamformer spatial filter. For each voxel in source space, a Hilbert envelope was derived yielding a timecourse showing fluctuations in the envelope of oscillatory power for each frequency band. These Hilbert envelopes were temporally smoothed (1s time resolution), and concatenated across subjects; the resulting dataset was analysed using temporal independent component analysis (ICA) to yield a set of 25 independent components per frequency band. The spatial signature of each temporal component (i.e. the maps in Fig. 1) was measured by Pearson correlation between the IC timecourse (extracted directly from ICA) and the timecourse of each voxel in the concatenated dataset. This process was implemented independently for each frequency band.

Quantitative comparison between RSN maps derived using MEG temporal ICA, and RSN maps from spatial ICA in a previously published fMRI study[4] was undertaken using a spatial correlation coefficient metric. The statistical significance of this correlation was measured using Monte Carlo simulations which take into account spatial bias in beamforming brought about by the non-uniqueness of the MEG inverse problem[5].

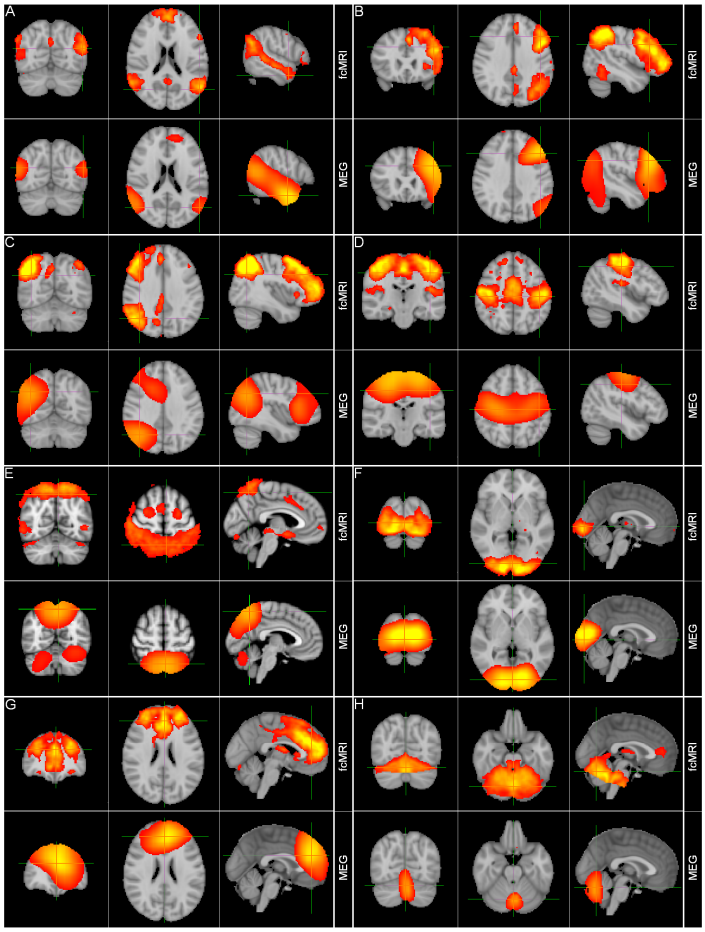

Fig. 1: Brain networks delineated using fMRI (upper panels) and MEG (lower panels). A-H show 8 independent components spatially matched

Results: 8 RSNs' spatial maps were unambiguously paired with RSNs derived from application of spatial ICA to resting state fMRI data[4] and these are shown in Fig. 1 (upper panels show fMRI; lower panels show MEG). Fig. 1A shows the default mode network with MEG data filtered into the α (8-13Hz) band. Separate network nodes were observed in medial frontal cortex and the left/right inferior parietal lobules as expected. Fig. 1B (β band) shows a left lateralised frontoparietal (attention) network whilst Fig. 1C shows a right lateralised mirror image. These 'attentional' networks have been widely reported in fMRI studies and show compelling similarity across modalities with a similar left-right split. Figs. 1 D – H (β band) show MEG based temporal components originating in the sensori-motor network (D), the medial parietal region (E), the visual cortex (F), the medial frontal cortex (G) and the cerebellum (H). In all cases spatially independent fMRI components can be found that match significantly the spatial signature of a MEG component.

Discussion and Conclusion: The above results show that the spatial structure of multiple resting state networks, identified reliably by fMRI, can also be independently measured using MEG. This finding confirms an electrophysiological basis to these networks and supports recent work[1,2,3,6] in showing that neural oscillations, particularly in the alpha and beta bands, play a role in network connectivity. The spatial resolution of fMRI is superior to that of MEG and this is clearly apparent from the results presented here. However, MEG offers a useful way to bypass the haemodynamic response and measure the electrophysiological basis of network activity and connectivity on a timescale relevant to brain function. It therefore follows that a multi-modal approach, using MEG and fMRI in conjunction, offers an excellent opportunity to study brain networks with high spatial and temporal precision. Work is currently underway to explore task-induced network changes using this methodology.

References: [1] Liu et al, NeuroImage 51: 102-111 (2010). [2] DePasquale et al, PNAS 107: 6040-6045 (2009). [3] Brookes et al, NeuroImage 56 : 1082-1104 (2011). [4] Smith et al, PNAS 106 : 13040-13045 (2009). [5] Brookes et al, PNAS 108: 16783-16788 (2011). [6] Mantini et al. PNAS 104: 13170-13175 (2007).

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