RECONSTRUCTING RESTING STATE BRAIN NETWORKS FROM HIGH-RESOLUTION EEG

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Target audience: Researchers and clinicians utilizing fMRI and/or EEG to study spatiotemporal patterns of the resting human brain in healthy and diseased states.

Purpose: The resting state networks (RSNs) have been broadly studied using BOLD fMRI data[1]. Since the BOLD fMRI is not direct measure of neural activations, the neurophysiological basis of the BOLD fMRI based RSNs is not fully understood. Recently RSNs have been derived from magnetoencephalography (MEG) signals, acquired in separate session than fMRI, by solving MEG inverse problems and showed that MEG based RSNs are of high spatial similarity with BOLD fMRI based RSNs[2]. We have also recently identified from simultaneously acquired EEG and fMRI resting state data, temporal independent EEG microstates (EEG-ms) that are related to BOLD RSNs, and demonstrated the temporal correlation among EEG-ms related RSN (EEG-ms-RSNs) and RSNs measured by BOLD fMRI (BOLD-fMRI-RSNs)[3]. However, the spatial characteristics of the RSNs in the EEG source domain, i.e. on the cortical surface, have not been yet fully studied. Additionally little is known about the temporal correlations between EEG based RSNs and BOLD-fMRI-RSNs from simultaneously recorded EEG and fMRI signals. Due to this gap in the knowledge, the investigation of neurophysiological basis of BOLD fMRI based RSNs and the comparison and validation of RSNs from different modalities data are difficult. In the present study, we aim to derive RSNs and their temporal dynamics from high-density EEG data only, recorded simultaneously with fMRI. We combined EEG inverse source imaging technique and independent component analysis (ICA) to obtain cortical distributions of RSNs from EEG. We compared EEG-ms-RSNs to the RSNs independently derived from simultaneously measured BOLD fMRI data. It is demonstrated that EEG-ms-RSNs and BOLD-fMRI-RSNs have significant similarity in spatial structure and high temporal correlations. This novel approach can be used to compare RSNs properties derived from different modalities.

Methods: Simultaneous resting-state EEG and fMRI were acquired from nine healthy human subjects (age 33 ± 10 years; one female). The experiments were performed on a General Electric Discovery MR750 3T MRI scanner with an 8-channel receive-only head coil. For the whole brain fMRI, a single shot gradient echo EPI sequence with Sensitivity Encoding (SENSE) and FOV/slice thickness/gap=220/2.9/0.2mm was used (TR/TE=2000/30ms, acceleration=2, image matrix 64×64, flip=30°, 34 axial slices). Structural MRI T1-weighted images were obtained with an MPRAGE sequence. High-density EEG signals from 126 channels were simultaneously recorded with fMRI scans using MRI-compatible BrainAmp MR Plus amplifiers (in 0.016–250 Hz band with 0.1 μV resolution and 5000 Hz sampling rate). Three closed-eye resting scans, each lasting six minutes and ten seconds, were acquired for each subject. A pneumatic respiration belt and a photoplethysmograph were used to obtain respiration and pulse oximetry measurements. A novel method was developed to analyze EEG-ms using electrophysiological source imaging (ESI) and ICA. After MRI and cardioballistic artifacts correction, ESI analysis was employed on the EEG topographies at the local peaks of global field power (defined as EEG-ms[4]) to estimate cortical source distributions. We modeled the sources for electrical potentials as current dipoles evenly distributed over the cortical surface. The volume conductor was modeled by a three-shell boundary element model with three different conductive tissues (the scalp, skull, and brain, with conductivities of 0.33 [S/m], 0.0165 [S/m], and 0.33 [S/m], respectively). Structural MRIs were segmented to build the realistic geometric models. The inverse problem was solved using minimum norm estimate[5] with the Tikhonov regularization[6]. The sources of EEG-ms were then subject to temporal ICA and decomposed into independent components (ICs), which are considered as the main microstates in the EEG source domain. Thus for each IC, the source map corresponds to the spatial topology of a specific type of microstate on the cortical surface and the intensity of the main microstate is reflected in the temporal trace of the IC, which is maximally independent from others. The time courses of main microstates were convolved with a canonical hemodynamic response function and down-sampled to TR. Thus we have identified cortical representation of EEG-ms or EEG-ms-derived RSNs (EEG-ms-RSNs) and their corresponding time courses. The preprocessed fMRI data were subject to group spatial ICA in order to extract BOLD RSNs. The source maps of EEG-ms were compared to the spatial maps of RSNs independently derived from BOLD fMRI (BOLD-fMRI-RSNs) and the correlation of their time courses were assessed.

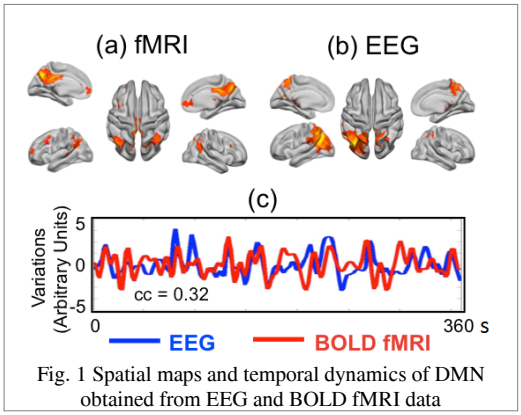

Fig. 1 Spatial maps and temporal dynamics of DMN obtained from EEG and BOLD fMRI data

Results: Eight EEG-ms-RNSs were identified, i.e. the default mode, left frontoparietal, right frontoparietal, sensorimotor, executive control, auditory, and visual networks[7], which are exactly same as RNSs obtained from BOLD fMRI data. The EEG-ms-RSNs were matched to BOLD-fMRI-RSNs according to their spatial correlations. The maps of EEG default mode RSNs are displayed in Fig. 1, which indeed indicate a high spatial similarity between EEG based RSNs and BOLD fMRI based RSNs. Notably two EEG based RSNs of the visual cortex were identified to be similar to the two visual BOLD-FMRI-RSNs: one consists of left or right primary visual cortex toward medial walls of both hemispheres, and another one is more lateral, including left and right extrastriate visual cortex and part of the parietal cortex. Fig. 1(c) also shows the temporal traces of BOLD fMRI data from the default mode RSN and the temporal traces of EEG data after convoluting the hemodynamic response function. These two traces show a high temporal correlation. The quantitative metrics, i.e. correlation coefficients, were calculated on both spatial maps and time courses of EEG-ms-RSNs and BOLD-fMRI-RSNs. While all spatial correlations are significant (p<0.005), most temporal correlations (except the lateral visual RSN) are also significant (p<0.05).

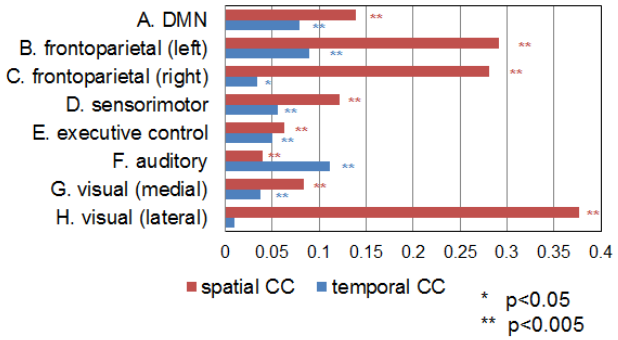

Fig. 2 Spatial and temporal correlation coefficients eight RSNs obtained from EEG and BOLD fMRI

Discussion & Conclusion: We develop a method to reconstruct RSNs from high-density EEGs. We have identified similar number of EEG-ms-RNS as we usually obtain from BOLD fMRI data. All EEG based RSNs are of high spatial similarity with independently derived from BOLD-FMRI-RSNs and, all but one EEG based RSNs are also of high temporal correlation with BOLD-FMRI-RSNs. The identification of EEG based RSNs was achieved by combining of microstate concept, ESI, and ICA techniques. Our approach has important advantage from the previous studies in obtaining RSNs from MEG data, because EEG and fMRI signals were simultaneously recorded and both measurements reflect the same brain spatio-temporal activations. While we have demonstrated the high degree of spatial and temporal similarities between EEG and fMRI based RSNs, some discrepancies among both RSNs can also be observed, such as in the temporal dynamics of the lateral visual networks. Our novel approach further elucidate electrophysiological signature of BOLD resting state networks, and demonstrate the intrinsic connection between fast neuronal activity and slow hemodynamics fluctuations.

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