High-density electroencephalography permits the detection of resting state networks

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Background: The existence of resting state networks (RSNs) in the human brain has been largely documented by functional magnetic resonance imaging (fMRI) and magneto-encephalography (MEG) studies [1-6]. However, no research group has been able to map brain networks using EEG recordings so far. In this study, we demonstrate that high-density EEG (hdEEG) can be used to detect RSNs.

Methods: We collected 5-minute resting state hdEEG (256 channels) signals, electrode positions and T1-weighted structural MRI in 19 subjects (age 28±5.9 years, 14 females). We developed a dedicated processing pipeline (Fig.1), which included 4 main processing steps: 1) ICA-based EEG artifact reduction [7]; 2) creation of 12-tissue realistic head model using a 12-layer finite element method (FEM) to estimate how electrical signals transmit from each brain source to the sensors [8]; 3) reconstruction of brain activity by the eLORETA method [9]; 4) temporal ICA on downsampled (1Hz) power time series of voxels. After estimating the component maps in individual space, we warped them to MNI space, and selected the EEG RSNs by matching them with fMRI-RSN templates. Finally, group-level RSN maps were generated by means of a random-effect analysis [10], using a voxel-wise non-parametric permutation test (RANDOMISE in FSL).

Results: We identified 14 RSNs (group-level: N=19, p<0.001, TFCE corrected) from hdEEG data (Fig. 2). These 14 RSNs are: default mode network (DMN), dorsal attention network (DAN), ventral attention network (VAN), right frontoparietal network (rFN), left frontoparietal network (IFN), language network, opercular network (CON), auditory network(AN), ventral somatomotor network (VSN), dorsal somatomotor network (DSN), visual foveal network (VFN), visual peripheral network (VPN), medial prefrontal network (MPN) and lateral prefrontal network (LPN). Fig.3 shows the spatial correlation between EEG-RSNs and fMRI-RSNs. Furthermore, to test the robustness of the pipeline, we split the continuous 5-minute hdEEG into 2 pieces of 2.5-minute signals (segment 1 and segment 2). Fig.4 displays the spatial maps of 14 RSNs generated by segment 1 and segment 2 respectively, whereas Fig.5 shows the spatial correlation between them.

Conclusions: We developed a complete analysis pipeline to detect RSNs spatial maps using hdEEG recordings. Our work suggests that hdEEG can be used as an alternative to MEG to investigate the electrophysiological basis of functional networks.
Reference
Fig. 1 – Processing pipeline to detect RSNs by hdEEG. To get the individual RSN spatial maps, several steps are involved: 1) EEG preprocessing to remove the noise; 2) realistic head volume conductivity model to demonstrate how electrical signals transmit from the each dipole source to the scalp sensors; 3) inverse solution to estimate the source oscillations based on the scalp distribution; 4) temporal ICA in the power time series of voxels to extract the temporal ICs, and then get the voxel-by-voxel correlation map between temporal ICs and the power series. After estimating the component maps in individual space, we warped them in MNI space, and selected the EEG RSNs based on fMRI templates.
Fig. 2 – Comparison of fourteen RSNs obtained from hdEEG (N=19, p<0.001, TFCE corrected) with fMRI-RSNs. These networks were selected and labeled on the basis of the spatial overlap with fMRI networks. Coronal, sagittal and axial views are shown. (A) DMN; (B) DAN; (C) VAN; (D) rFPN; (E) lFPN; (F) LN; (G) CON; (H) AN; (I) VSN; (J) DSN; (K) VFN; (L) VPN; (M) MPN; (N) LPN. (A-N) Upper, hdEEG; Lower, fMRI.
Fig. 3 – Spearman spatial correlation between RSNs obtained by hdEEG and RSNs from fMRI.
Fig. 4 - Spatial maps of RSNs from EEG segment 1 and segment 2. We split the hdEEG recordings into two segments: the first 2 minutes and 30 seconds (segment 1) and the first 2 minutes and 30 seconds (segment 2). The group-level RSNs maps obtained from the two EEG segments are directly compared (threshold: \( p < 0.001 \), TFCE corrected). (A) DMN; (B) DAN; (C) VAN; (D) rFPN; (E) lFPN; (F) LN; (G) CON; (H) AN; (I) VSN; (J) DSN; (K) VFN; (L) VPN; (M) MPN; (N) LPN. (A-N) Upper, RSNs from segment 1; Lower, RSNs from segment 2.
Fig. 5 - Spearman spatial correlation between the RSNs from EEG segment 1 and EEG segment 2.