Correspondence Between Resting State Networks and EEG-Correlated FMRI Maps

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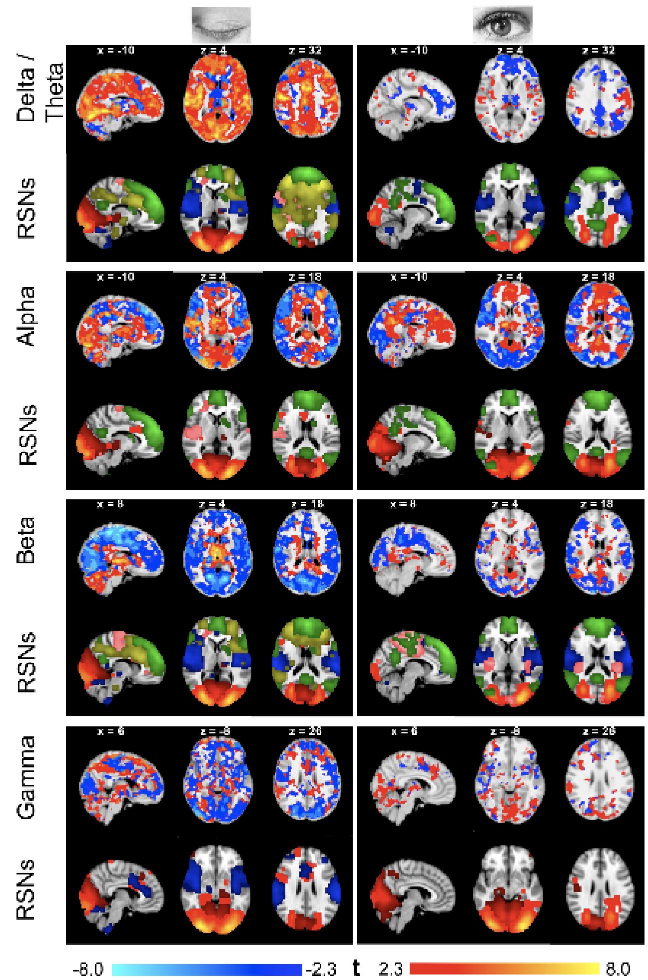
Introduction: Both functional magnetic resonance imaging (FMRI) and electroencephalography (EEG) show interesting and structured phenomena during rest; i.e. Resting State Networks (RSNs) in FMRI and rhythmic oscillations in EEG. In addition, many studies have now shown FMRI activation maps derived from EEG rhythms. Mantini el al. [1] have demonstrated that some temporal correlation exists between the average, scalp-wide EEG power in different bands, and some RSNs. Moreover, recent preliminary work of ours has shown widespread FMRI brain activation due to rhythmic activities in all EEG frequency bands, obtained by pre-decomposing the EEG data using Independent Component Analysis (ICA) [2]. However, there remains a question of whether these activations are of direct relation to RSNs. In this work, we show that EEG-correlated FMRI maps obtained under different conditions (eyes open and eyes closed), are spatially similar to different RSNs obtained from the same FMRI data.



Methods: Eleven subjects participated and gave informed consent. FMRI was performed on a 3T GE HDx MRI scanner with simultaneous scalp EEG using a Brain Products, 32-channel system. Subjects underwent two (1st: eyes-closed, 2nd: eyes-open, fixated) T2*-weighted (BOLD) GE-EPI scans, each 20min in duration (TR=3s, TE=35ms, voxel-size: 3.2mm isotropic, 64x64 matrix, 45 slices). Pulse oximeter, respiration belt, and breath CO2 signals were also collected.

EEG data were cleaned of MRI gradient and ballistocardiographic artefacts and band-pass filtered into 4 frequency bands: 1-7Hz (delta/theta), 8-13Hz (alpha), 16-28Hz (beta), and 32-43Hz (gamma). Corrupted portions (e.g. gross movement artifacts) were excluded then temporal ICA was performed, yielding 31 ICs. Exclusion criteria was applied to exclude obvious artefactual ICs from further analysis based on a) scalp maps, b) power spectrum, and c) temporal characteristics. The number of included ICs, across all frequency bands, was typically between 40-60 for the eyes shut session, and 24-45 for the eyes-open. The ICA unmixing matrix was then applied to the contiguous data. The power time-course of each included IC was then computed, with corrupt portions replaced by the mean of the adjacent intervals.

For FMRI, RETROICOR [3] was first applied to remove respiratory and cardiac artefacts, followed by standard FMRI data pre-processing using FSL (www.fmrib.ox.ac.uk/fsl). Voxel-wise regression using GLM analysis was then performed. Each IC power time-course was included as one explanatory variable (EV) in the design matrix. Motion parameters and end-tidal CO2 EVs were also included. Positive and negative contrasts were tested for each EV and for all EVs contributing to one frequency (average activation in that frequency). F-tests across all contrasts in one frequency band were also performed. For the group analysis, all first-level statistical images were registered to standard space. Group activation was inferred using permutation testing on the zf-stats images. Group inference was performed using p<0.005, FWE-corrected for multiple comparisons by using the null distribution of the maximum TFCE (Threshold-Free Cluster Enhancement) value [4]. Unthresholded group average activations were used as a guide to impose directionality on the group f-test results. Group ICA on the FMRI data was also performed using the concatenation approach (separately for eyes-open and eyes-closed) (MELODIC in FSL). Six consistent RSN maps were identified by template matching to those published by Beckmann et al. [5]. The same RSNs were obtained in both conditions. EEG-FMRI activation maps for each band in a given condition were then visually compared with combinations of the RSNs from that condition.

Results: The figure shows group EEG-FMRI correlation maps, as well as the corresponding comparisons with group RSNs obtained from the same data. The left and right columns of the figure are the eyes-closed and eyes-open conditions, respectively. The four rows are the Delta/Theta, Alpha, Beta and Gamma bands. The top and bottom parts of each row are the EEG-FMRI maps and the corresponding RSNs, respectively. The six different RSNs in each image are colour-coded (the t-stat colour-bars refer to the EEG-FMRI results only). Widespread EEG-correlated FMRI activations are present in all frequency bands. In the Delta/Theta band, positive activation is visible in all of cortex, with negative activation in thalamus. When eyes are open, most of the activation diminishes except for a negative default mode network (DMN). Beta activation / RSN results are similar to theta / delta but in a reversed correlation direction, with an increase in thalamus involvement. Alpha results in the eyes-closed session show mainly positive thalamus and primary visual activation, with negative correlation in other cortical areas. In eyes-closed, primary visual correlation turns negative and positive DMN activation is observed. Chosen combinations of RSNs from the same data show close spatial similarities with EEG-FMRI activation maps. In gamma strong, negative visual cortex activation is observed, which decreases and reverses in polarity when the eyes are open.

Conclusions: Thalamus seems to be involved in the regulation of the observed EEG rhythmic activities. In the cortex, RSNs and EEG-correlated FMRI maps cover similar widespread areas. However, thalamus activation in the EEG-FMRI maps was not reflected in the RSNs. Additional investigation is needed to examine the presence of the thalamus in the RSNs as well as the significance of the correlation direction with respect to RSNs.

References: [1] Mantini et al., *PNAS,* 4 (32):13170 –1317 (2007). [2] Niazy et al., *proc.14th OHBM* (2008). [3] Glover et al. *MRM* 44:162-167 (2000). [4] Smith & Nichols, *Neuroimage.* 1;44(1):83-98 (2009). [5] C. F. Beckmann et al., *Phil. Trans. R. Soc.* B 360:1001–1013, (2005).