# Investigating the neural basis of the default mode network using blind hemodynamic deconvolution of resting state fMRI data

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**Introduction:** Default mode network (DMN) is one of the most important resting state networks (RSNs) in the brain which has been extensively investigated using functional magnetic resonance imaging (fMRI). Since the fMRI time series at each voxel is the convolution of an underlying neural signal with the hemodynamic response (HRF), there is a debate on whether the DMN has a neural origin or is at least in part (or at most fully) a consequence of hemodynamic processes and physiological noise that arise due to cardiac pulsation and respiration. In order to investigate this, we performed blind hemodynamic deconvolution of resting state (RS) fMRI data that was acquired with different repetition times and magnetic field strength. Subsequently functional connectivity maps were found using seed based correlation analysis on latent neuronal signals with a posterior cingulate seed in order to identify the DMN. The basic anatomical structure found with deconvolved fMRI data was very similar to that found using fMRI data pre-processed using standard procedure. This provides strong evidence that the DMN has a neural origin and cannot be just a consequence of hemodynamic processes and physiological noise. Also, blind deconvolution provides a convenient way of obtaining RS brain networks from neural oscillations without potentially removing physiological fluctuations in BOLD data which have been recently shown to be related to neuronal processes.

**Table 1:** Data acquisition Parameters

| Magnetic field strength | Sequence | TR (ms) | Voxel size (mm$^3$) | Acquisition matrix | No. of subjects | We Refer in this paper as |
|---|---|---|---|---|---|---|
| 3 Tesla | EPI | 1000 | 3.5 x 3.5 x 6 | 64 x 64 x 16 | 24 | 3T1s |
| 3 Tesla | MB-EPI | 600 | 3.5 x 3.5 x 6 | 64 x 64 x 16 | 9 | 3T.6s |
| 7 Tesla | MB-EPI | 2000 | 2 x 2 x 3 | 64 x 64 x 16 | 12 | 7T1s |
| 7 Tesla | MB-EPI | 1000 | 2 x 2 x 3 | 64 x 64 x 16 | 12 | 7T2s |

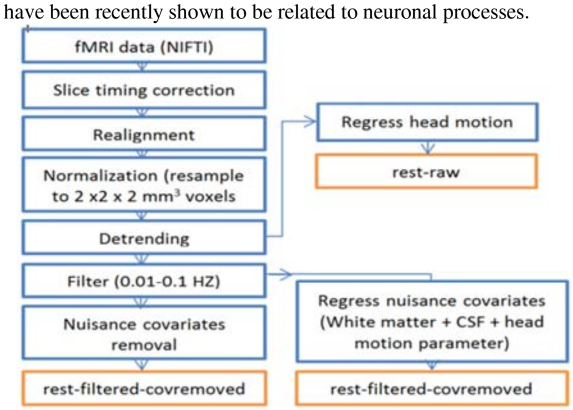


**Figure 1:** A schematic illustrating three different fMRI pre-processing pipelines corresponding to rest-raw, rest-covremoved and rest-filtered-covremoved data

**Method:** Resting state fMRI data were collected using Single-shot gradient-recalled echo planar imaging (EPI) and Multiband EPI (MB-EPI) sequence [1] with the parameters shown in Table 1. The data was preprocessed as shown in Figure 1 and analyzed using SPM8 [2], DPARSF [3] and REST [4] toolboxes. The whole data was divided into three categories based on the preprocessing steps and called "rest-raw", "rest-covremoved" and "rest-filtered-covremoved" (Fig 1). Blind hemodynamic deconvolution of resting state data was applied only to the rest-raw and rest-covremoved data to remove the HRF from the fMRI data so as to obtain underlying latent neural signals using the approach proposed by Wu et al [5]. A seed based correlation analysis (SCA) with a seed at the posterior cingulate cortex (PCC), was applied to deconvolved rest-raw data, deconvolved rest-covremoved data and rest-filtered-covremoved data to get functional connectivity (FC) maps. These maps were then subjected to one-sample t-test (corrected $p<0.01$) [6,7] to get the group FC t-map. The FC maps obtained from each of the four groups (3T.6s, 3T1s, 7T1s and 7T2s) for pre-processed fMRI data (i.e. rest-filtered-covremoved) and latent neural signals (i.e. deconvolved rest-raw & deconvolved rest-covremoved), were compared to obtain a map of the DMN with voxels commonly found in all the groups. Finally, the overlap between the common DMN maps obtained from fMRI and latent neural signals was investigated (Fig 2).

**Results and Discussion:** The DMN map obtained from latent neural signals and pre-processed fMRI data with voxels commonly found in all the groups is shown in Fig 2(a) and Fig 2(b) respectively. The overlap between Fig 2a & 2b is depicted in Fig 2(c). These figures demonstrate that the core regions of the DMN, i.e. posterior cingulate cortex (PCC), bilateral inferior parietal lobule (IPL) and medial prefrontal cortex (mPFC), were found irrespective of field strength, TR or preprocessing strategies using both fMRI data as well latent neural signals. Fig 2(c) demonstrates that there is a large overlap between the DMN obtained from fMRI data as compared to that obtained from latent neural signals. Additionally, the DMN obtained from latent neural signals was more specific to the gray matter. We observed that 92% of its voxels were in the gray matter as opposed to only 76% of the voxels in the DMN obtained from fMRI data being in the gray matter**.** The result proves that the DMN has a neural origin and cannot be a consequence of hemodynamic artifacts. Also, blind deconvolution provides a convenient way of obtaining RSNs from neural oscillations without potentially removing physiological fluctuations in BOLD data which have been recently shown to be related to neuronal processes.

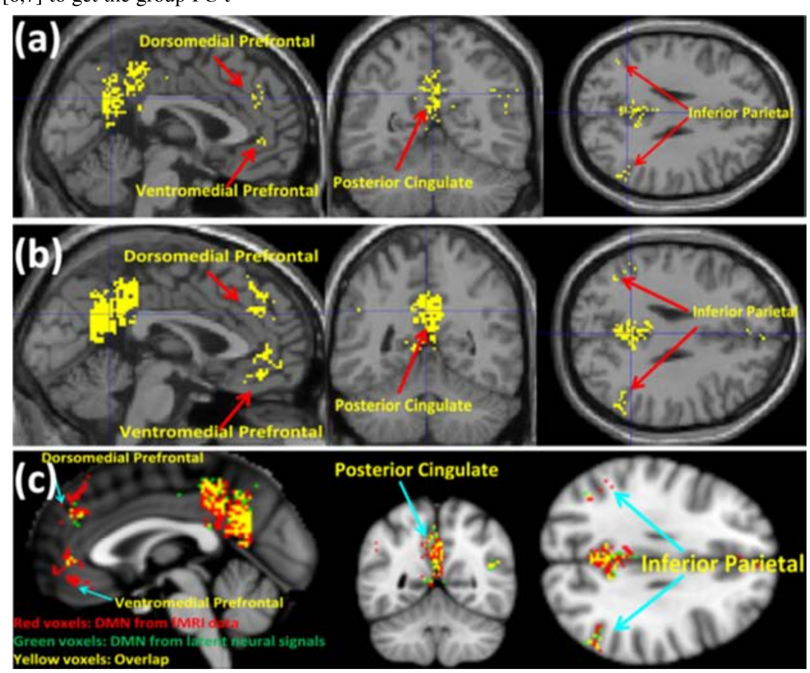


**Figure 2:** A map of the DMN with voxels commonly found in all the four groups (3T.6s, 3T1s, 7T1s and 7T2s) obtained from (a) latent neural signals (b) preprocessed fMRI data (c) overlap between latent neural signals and preprocessed fMRI data

**References: 1)** DA Feinberg et al.,*PLos One*, 5(12), 2010 **2)** KJ Friston et al., *Human Brain Mapping*, 2(4), 189-210, 1995. **3)** Y Chao-Gan et al.,*Front Syst Neurosci*, 4(13), 2010 **4)** Xiao-Wei Song et al.,*PLoS ONE*, 6(9), 2011 **5)** GR Wu et al., *Med Image Anal.*,17(3), 365-374, 2013 **6)** MJ McKeown et al., *Hum Brain Mapp.*, 6(3), 160-188, 1998 **7)** VD Calhoun et al., *Magn Reson Med.*, 48(10), 180-192, 2002