Spontaneous Low-frequency Fluctuations in the Thalamus: Evidence from 3T and 7T Resting-state fMRI

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Introduction:

Research interests on the study of functional MRI during resting state (RS-fMRI) have demonstrated a consistent pattern of slow fluctuations in the blood oxygenation level dependent (BOLD) signal referred to as the "default mode" of brain function [1]. Such spontaneous neuronal activity plays a role in maintaining baseline human cognition and metabolic equilibrium in the resting brain. The thalamus, as the centrally located relay station for transmitting information throughout the brain, participates in communication with many associative brain regions and involves global multi-functional pathways. The purpose of this study was to investigate whether the 7T resting-state functional scans can give us more information on this low frequency resting state network (RSN) associated with thalamic function.

Method:

Twenty right handed healthy subjects (ranging in age from 23 to 49, with a median age at 36 years, mean age at 35 years old, including 14 males and 6 females) were studied. All subjects were recruited after meeting the following inclusion criteria: no history of alcohol or drug abuse; no history of neuropsychological diseases before injury; and no history of other neurologic diseases including stroke, epilepsy, and somatic disorders.

Seventeen subjects were scanned on a 3T Siemens Trio whole body MR scanner (Siemens Medical System, Erlangen, Germany), and four subjects were scanned on 7T Siemens Opera whole body MR scanner. In addition to conventional T2-weighted imaging, twenty T1-weighted anatomic images were collected parallel to AC-PC line with 5mm slice thickness and 1mm gap and positioned to cover the whole cerebrum. The functional images were collected in the same planes, using a gradient echo EPI sequence: TR/TE=2s/30ms, flip angle=70^{o}, FOV=22x22cm^{2} and acquisition matrix size=128x128 for 3T; and TR/TE=2s/25ms, flip angle=60^{o}, FOV=25x25cm^{2} and acquisition matrix size=128x128 for 7T. Parallel imaging (GRAPPA factor=2) was performed with the vendor provided GRAPPA Algorithm in EPI at 7T scans. Then a whole brain 3D T1-weighted MPRAGE sequence were also acquired. During the two RS-fMRI sessions, all subjects were instructed to close eyes but keep awake. Each scan lasted 5 minutes and 6 seconds. The repeated RS-fMRI was also performed in 2 volunteers at 3T scanner from different days.

All MRI data were analyzed using SPM2 (Statistical Parametric Mapping, http://www.fil.ion.ucl.ac.uk) and MRIcro (http://www.mricro.com) and additional in house programs running under MATLAB (Mathworks, Natick, MA). fMRI data were preprocessed for the analysis by first motion corrected, realigned, co-registered, then registered to standard Talaraich coordinates and spatial smoothed in SPM2. We used the signal from the seed regions – bilateral thalamus to define the reference time course, then calculated the correlation coefficient to all voxel's time series within the whole brain to generate a functional connectivity map. Fisher's z' transformation was used to compute Fisher's z' maps for each subject, and then one sample T-test was performed to quantitatively get group contrast maps which show all areas that are significantly correlated to the seed ROIs (r>0.6 so z'>0.55).

Results:

In healthy volunteers at 3T scans, a consistent pattern of thalamic functional activation map was found in different sessions including data acquired in the same day or different days. The thalamic functional network shown on RS-fMRI includes both sides of the thalamus (Figure 1, 1st row). This pattern was consistent when the seed regions were placed in either the right or left side of thalamus. The functional connectivity with thalamus for all healthy volunteers showed a very clean, focused functional network, none of the normal controls showed diffuse functional connectivity at this level of the significance (r>0.6). Some brain regions, such as caudate nucleus, anterior cingulated and posterior cingulate, which are less significantly (r>0.4) correlated to the thalamus were also showed in the 2nd row of Figure 1.

In healthy volunteers at 7T scans, we got similar pattern of thalamic RSN which include both sides of the thalamus at a higher level of the significance r>0.8 (Figure 2, 1st row). However, the correlation result at significance level of r>0.6 obtained from 7T scans (Figure 2, 2nd row) showed even more diffuse functional connectivity than the correlation result at significance level of r>0.4 obtained from 3T scans (Figure 1, 2nd row). It includes not only those medial brain areas, but also some outer layer of the cerebral cortex such as cuneus, insula, central and frontal gyrus.

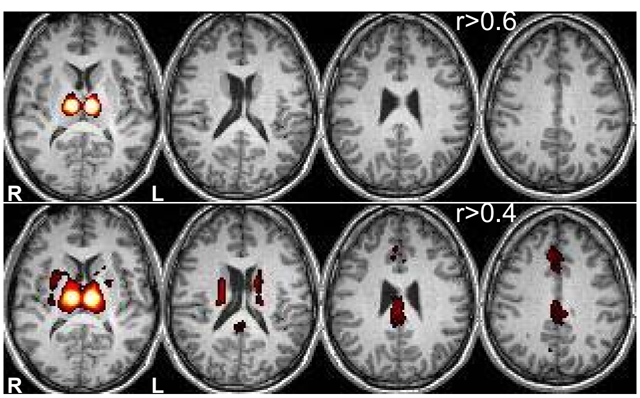

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Figure 1. Group thalamic RSN calculated from images obtained from 3T scans. It shows results at different level of significance.

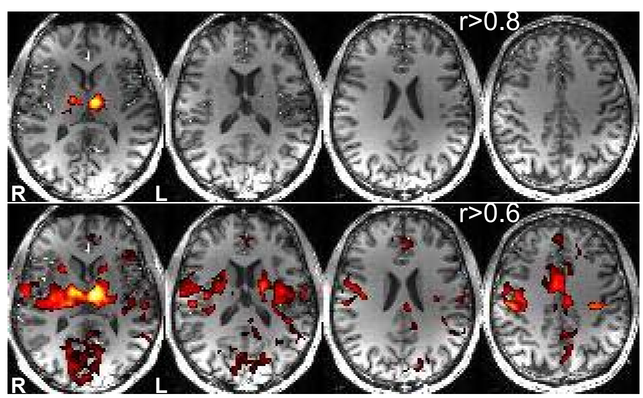

Figure 2. Group thalamic RSN calculated from images obtained from 7T scans. It shows results at different level of significance.

Conclusion & Discussion:

The cortex is sending the information to and from subcortical structures such as the thalamus and the basal ganglia via connections. Most sensory information is routed to the cerebral cortex via the thalamus. The thalamus is important to communication among many associative brain regions including sensory, motor, cognitive, and behavior and it is one of the key elements of neuronal organization in the global function of the brain related to the rich thalamocortical interconnectivity[2]. This study demonstrates for the first time, the thalamic functional network during resting state obtained from both 3T and 7T scans in healthy volunteers. Thalamus was implicated to be primarily involved with motor control based on results from 3T scans. Meanwhile thalamus was showed to be functionally related to a number of more brain areas from 7T scans. The 7T scan verified the larger functional network of thalamus in brain neural activity and demonstrated that the thalamus is involved in regulating the transmission of information regarding visual, motor control, perception, some cognitive functioning and so forth. We will test some other functional networks to see if 7T give us more information, too.

Reference: [1] Fox MD, Raichle ME. Nat Rev Neurosci 2007; 8(9): 700-11. [2] Guillery, R.W., J Anat, 1995. 187 (Pt 3): 583-92.

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