Thalamic relay of frequency-specific EEG scalp field maps

Simon Schwab[1], Thomas Koenig[1], Andrea Federspiel[1], Thomas Dierks[1], and Kay Jann[1]
[1]*Dept. of Psychiatric Neurophysiology, University Hospital of Psychiatry / University of Bern, Bern, Switzerland*

Introduction: The thalamus is a fundamental relay structure of the brain that transfers sensory and motor signals to distinct zones of the cerebral cortex. Structural and functional MRI has been used to map the thalamocortical system of the resting brain and revealed concordant networks [1]. The thalamus has also been argued as the pacemaker of cortical rhythms observed by EEG [2]. Recently, EEG microstates that represent states of synchronized brain activity [3] and EEG spectral fluctuations [4] have been associated to fMRI resting state networks (RSNs). However, the emergence of specific scalp field oscillations and associated thalamic BOLD signal fluctuations has not yet been studied. In the present work, we aimed to define the frequency specific thalamic areas generating distinct synchronized cortical networks, as indexed by EEG scalp fields oscillating with a common phase.

Methods: Fourteen healthy subjects (6f/8m, mean age 26±2.7 years) underwent simultaneous EEG/fMRI in a no-task condition with eyes closed and not falling asleep (resting state). All subjects were measured in the morning and had no caffeine, nicotine or alcohol 10 hours prior to the experiment. They had no history of neurological or psychiatric disease and were free from illegal drugs or psychoactive medication. MRI data were acquired with a 3T Siemens Magnetom Trio, functional data using a EPI sequence (252 volumes, 32 slices, 3x3x3 mm3, gap thickness 0.75 mm, matrix size 64x64, FOV 192x192 mm2, TR/TE 1980ms/30ms. EEG data were acquired with a 96 channel MR compatible system (Brain Products, Germany). Preprocessing of fMRI data included slice-time and motion correction, co-registration to anatomical data and normalization to standard Talairach space. EEG preprocessing included RF-artifact correction using average artifact subtraction and ballistocardiogram correction by ICA. EEG timecourses were then downsampled to 100Hz, and filtered between 1-20Hz and epochs exhibiting residual artifacts (eyes, muscles, etc) were removed. The cleaned EEG was then subjected to a Topographic Time-Frequency Decomposition algorithm [5] that decomposed the EEG into 6 classes of transient states of synchronized oscillations. First, in single-subject GLMs, the BOLD response was fitted by using the 48 timecourses (6 classes of states x 8 frequency bands) as predictors, which were previously convolved with the canonical haemodynamic response function. From the resulting individual beta-maps, effects that were independent of state-class were eliminated by subtraction. In the group analysis, we used voxel-wise one-way ANOVA with the 8 frequency bands as within factor to fit the beta values of the GLM. For each of the six state-classes, a statistical map with F values of the main effect of frequency was created (Bonferroni, $p < 0.05$).

Results: Frequency specific areas were identified for the different state-classes (Maps) in distinct medial and lateral thalamic subregions (Figure 1). Corresponding thalamic nuclei are listed in Table 1 together with their known cortical projection.

Table 1: Frequency-dependent BOLD response in the thalamic structures for 6 EEG state-classes.

	Thalamic BOLD response	Cortical projection
Map 1	- DM (bilateral) - VPL (bilateral)	- Prefrontal cortex - Somatosensory cortex
Map 2	- VL (bilateral) - Pul (bilateral)	- Motor cortex - Parietal, occipital and temporal lobes
Map 3	No thalamic response	
Map 4	- VL (left)	- Motor cortex (left)
Map 5	- LP (left) - Pul (left)	- Parietal lobe (left) - Parietal, occipital and temporal lobes
Map 6	- DM (bilateral) - VL (bilateral) - LP (left)	- Prefrontal cortex - Motor cortex - Parietal lobe (left)

DM: Dorsomedial nucleus, VPL: Ventral-posterolateral n., VL: Ventral lateral n., Pul: Pulvinar, LP: lateral posterior n.

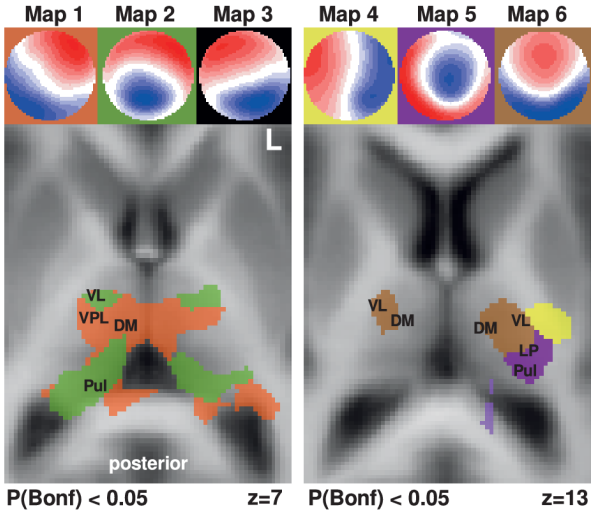

Figure 1: Frequency dependent thalamic regions for the 6 state maps. For map 3 no thalamic response could be identified.

Discussion: In the past, cortical BOLD fluctuations have successfully been correlated with thalamic BOLD to determine the functional thalamo-cortical connectivity [1]. In this study, we have identified a consistent topological mapping of thalamic regions to a set of spatially defined patterns of cortical common phase oscillations at specific frequencies. Since thalamic activity itself is not visible in the EEG, the observed EEG-BOLD relations must be functional, attributing the thalamus a role of mediator, modulator and coordinator of cortical oscillatory activity that is visible in EEG. Synchronization of cortical oscillations is an important candidate mechanism for network formation and feature binding. Therefore, our study provides a novel way to elucidate the systematics of subcortical effects on the formation of large scale cortical networks.

References: 1. Zhang, D, et al. Cereb Cortex. 2010;20(5):1187–1194. 2. Lopes da Silva, F. Electroencephalogr Clin Neurophysiol. 1991;79(2):81–93. 3. Britz, J, et al. Neuroimage. 2010;52(4):1162–1170. 4. Jann, K, et al. PLoS One. 2010;5(9):e12945. 5. Koenig, T, et al. Neuroimage. 2001;14(2):383–390.