Anesthesia modulated correlation between spontaneous fMRI BOLD and local field potentials in rat somatosensory cortex

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Introduction: Synchronized spontaneous neural activity between distant cortical areas has been frequently observed by electrophysiology and is assumed to be the mechanism underlying correlated fluctuations in the magnetic resonance imaging (MRI) signal that are used to map functional connectivity at rest [1,2]. However, the neural basis of MRI resting-state functional connectivity has not been fully investigated, due to the technical challenges involved in simultaneous imaging and recording [3]. We have developed combined imaging and recording techniques for the rat model, which allows the simultaneous measurement of the spontaneous fluctuations and inter-hemispherical functional connectivity via fMRI and electrophysiology.

Materials and methods: 5 SD male rats, 200-300g, were anesthetized with medetomidine or isoflurane and glass microelectrodes were implanted in bilateral primary somatosensory cortex. The rat was then transferred to a 9.4 T Bruker MRI system. A coronal slice was positioned so that it included the electrode tips and MRI and local field potentials (LFPs) were simultaneously acquired. Images were acquired with a GE-EPI sequence (relaxation time=500ms/echo time=24ms, 0.3 x 0.3 mm^2 in plane actual resolution) that lasted 8.3 minutes. LFPs were amplified x1000 and digitized at 12 kHz. The artifacts induced in the electrophysiological data by the changing magnetic fields required for image acquisition were removed by subtracting noise structure, which was extracted by averaging periodic scans. The saturated sections due to read-out gradients, which occupied 22/500 of each scan cycle, were refilled with the values computed from a linear function which passes each time point before and after gradient noise (see figure 1). The low-frequency power time courses (delta and theta) were obtained with 2-second windows since modulated gradient sections may have minimum effects on low-frequency power spectrum analysis. The high frequency power time courses (alpha, beta and gamma) were obtained with restraining windows between neighboring gradients, which are approximately 0.5-second each. The correlation coefficients were computed between bilateral somatosensory LFPs or LFP-power time courses in various frequency bands as well as simultaneously measured low-frequency (0.01~0.25 Hz) BOLD time courses.

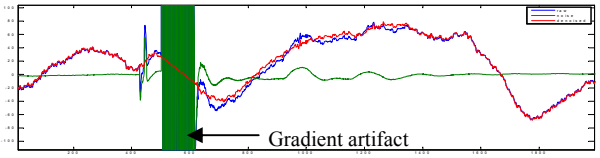

Figure 1. By zooming in one of scan cycles (~500 ms), it shows that the artifacts (green) during imaging may be removed from original recordings (blue). The denoised time courses (red) were used for further correlation analysis.

Results and Discussions: The preliminary results showed strong inter-hemispheric synchronization for low-frequency BOLD signals as well as power of LFP fluctuations in low frequency ranges. The cortical areas implanted with electrodes exhibit high correlation between LFP power and low frequency BOLD signal fluctuations, localized to the cortex surrounding the electrode and analogous areas in the contralateral hemisphere (see figure 2). The highest correlation between the measurements of different modalities is in low frequency band (delta, 1~4 Hz or theta, 4~8 Hz). The BOLD signal lags the electrical signal by ~2-4 seconds, on the order of the hemodynamic delay previously observed in the rat [4]. The correlation of measurements from the two different modalities can be modulated by anesthesia type and state. The BOLD time delays and peak duration are longer for rats anesthetized by isoflurane (figure 2A) than by medetomidine (figure 2B). One possible reason may be different vascular impact for the two anesthetics. The isoflurane may cause vascular dilation which might result in less vascular tension and slow down the hemodynamic response. On the contrary, the medetomidine may cause vascular constraint, which might result in higher vascular tension and speed up the hemodynamic response. Future work will focus on assessing the reproducibility of the results by increasing the number of rats and developing more detailed analysis of the relationship between the two measurements on functional connectivity.

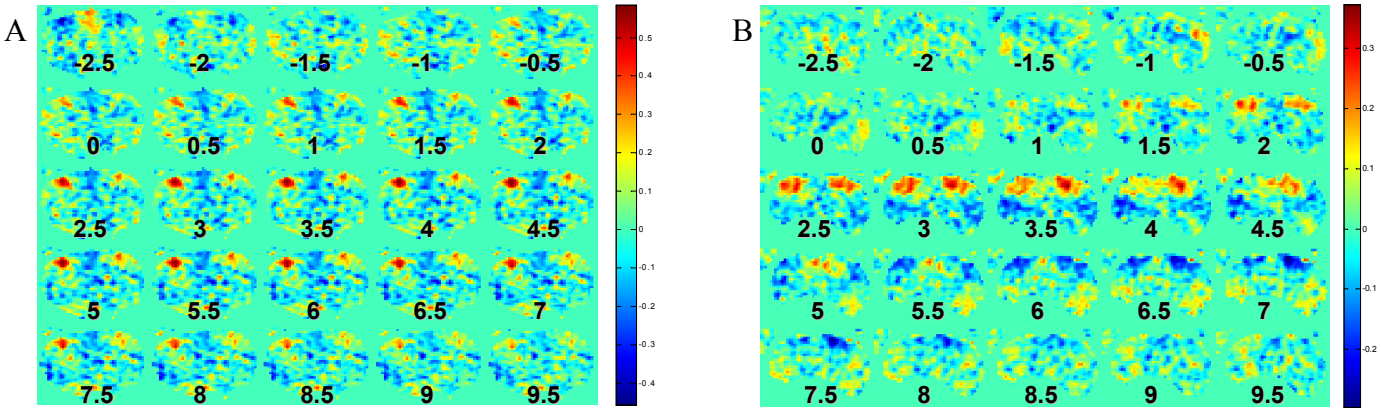

Figure 2. Coronal maps (from one typical rat) of correlation between power of delta (A) or theta (B) band LFPs spontaneous fluctuation from one electrode and BOLD signal at time lags from -2.5 to 9.5 s. Maximum correlation is observed in bilateral SI at approximately 3s for the state anesthetized by medetomidine (B), 5s for the state anesthetized by isoflurane (A). Color bar represents Pearson r.

References: [1] Drew, P.J. et al., Nature Neurosci 2008, 11(9): 991-993; [2] Shmuel, A. and D. A. Leopold, HBM 2008, 29(7): 751-761; [3] Logothetis N. K., et al., Nature 2001, 412(6843): 150-157; [4] de Zwart, J.A. et al., Neuroimage 2005, 24(3): 667-677