0.1-Hz oscillation in fMRI BOLD signals and full-band LFPs in rat cortex

Wen-Ju Pan[1], Garth Thompson[1], Jacob Billings[1], Josh Grooms[1], Sadia Shakil[1,2], and Shella Keilholz[1]

[1]*Biomedical Engineering, Emory University/ Georgia Institute of Technology, Atlanta, GA, United States,* [2]*Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, United States*

Target audience Researchers focusing on infraslow neural activities and neurovascular coupling in resting-state fMRI.

Purpose Resting-state fMRI assumes neurovascular coupling between hemodynamics and spontaneous slow neural activities in cycle ranges of 10 sec to 100 sec. However, vascular contributions from the omnipresent vasomotion of blood flow flux (typically ~0.1 Hz[1]) may certainly overlap this frequency range and could complicate the slow BOLD signal. As yet little is understood about the relationship of resting-state fMRI BOLD signals, 0.1-Hz vascular oscillations and the neural contribution at ~0.1 Hz. Here we use a measure of simultaneous fMRI and full-band LFP recording in rat cortex to explore this relationship.

Methods Six SD rats, male 250-300g, were used in this study. Micro glass electrodes (Ag/AgCl) were implanted in bilateral somatosensory cortex (S1FL) and intracortical LFPs were recorded during the fMRI scans. The rats were anesthetized under 1.5% isoflurane and kept in normal physiological conditions during fMRI scan and LFP recording[2]. DC-amplifiers (A-M System, model 3000) were used in electrophysiological data collection and on-line filtered between 0 to 100 Hz. The resting-state scans were conducted in a Bruker 9.4T system. The GE-EPI parameters include TR/TE=500ms/15ms, slice thickness=2mm, single coronal slice including the sites of the bilateral implanted electrode tips, FOV=25.6mm, scan time = 8 min 20 sec each resting-state scan. The fMRI data sets were preprocessed in MATLAB and SPM8, including slice timing, motion correction, smoothing (in coronal plane with FWHM of 1.67 × pixel size), and linear drift removal. The concurrent cortical extracellular potentials and BOLD signals at same site were evaluated on their coherent slow variations at around 0.1 Hz. Coherence analyses were calculated between BOLD and infraslow LFP, as well as between infraslow LFP and band-limited powers (BLPs) of various bands (1-100 Hz). The BOLD signals are from ROI at the electrode tip with highest BOLD/infraslow LFP correlation across image with 4-sec lag for BOLD (not shown, refer to[2]). The coherence is a function of the power spectral density (P_{xx} and P_{yy}) of x and y and the cross power spectral density (P_{xy}) of x and y:

$$Cxy(f) = \frac{|Pxy(f)|^2}{Pxx(f)Pyy(f)}$$

Results The concurrent BOLD (after 4-sec lagged) and infraslow LFP show higher coherence below 0.1 Hz and peak close to 0.1 Hz for most rats (Fig.1. top). To further examine possible contributions to infraslow LFP components from high frequency LFPs (delta, theta, alpha, beta and gamma), the coherence analyses were conducted between infraslow LFP and band-limited powers of each LFP band (BLPs). The average results show a robust peak at identical frequency close to 0.1 Hz for gamma to alpha, but not the low-frequency bands of delta and theta (Fig.1. middle and bottom).

Discussion/Conclusion Resting-state fMRI primarily utilizes slow fluctuations of <0.1 Hz hemodynamic signals, which exhibit higher power and temporal correlation within functional networks. Vascular contributions at similar frequencies, termed 0.1-Hz vasomotion[1], make neurovascular coupling during slow spontaneous activity less straightforward than the well-characterized response to a stimulation. In present studies, we found the 0.1-Hz signal coupling exists not only between BOLD and LFPs but also between extracellular electrical signals of infraslow LFP and BLPs of gamma, beta and alpha bands. The findings suggest a strong interaction between slow vasomotion-like oscillations and neurovascular coupling in spontaneous activity, by which the resting-state BOLD signal might be maintained with high power over vasomotion frequencies, but certainly modulated by neurovascular coupling. Ca^{2+} signaling might play a key role to the interaction between vascular global calcium synchronization for vessel tone oscillation[3,4] and neurovascular coupling mediated by astrocytic endfoot[5]. To more fully understand the phenomena, multi-parameter measures will be necessary. Further measurements in future involving localized total hemoglobin by intracortical recordings of optical spectroscopy and cellular calcium signals would greatly gain understanding to the interaction between vascular signal and BOLD signal during slow neural activity at resting state.

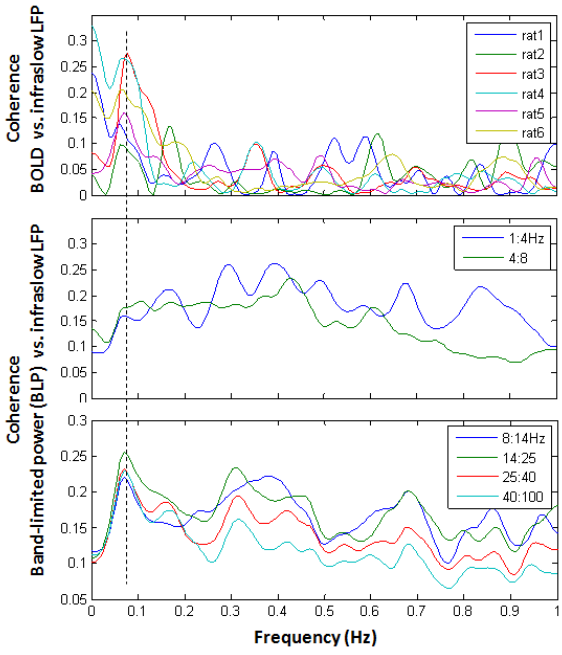

Figure 1. Coherence peak at ~0.1Hz for BOLD and LFPs (top) Most rats show high coherence between BOLD and infraslow LFPs. The high frequency, from alpha to gamma, band-limited power of LFPs (BLPs) show identical peak coherence with infraslow LFPs close to 0.1 Hz (bottom), but the low frequency bands of delta and theta (middle) do no exhibit the peak.

References

1 Mayhew, J. E. W. *et al.* Cerebral vasomotion: A 0.1-Hz oscillation in reflected light imaging of neural activity. *Neuroimage* **4**, 183-193 (1996).

2 Pan, W. J., *et al*. Infraslow LFP correlates to resting-state fMRI BOLD signals. *Neuroimage* **74**, 288-297, (2013).

3 Jaggar, J. H., *et al*. Calcium sparks in smooth muscle. *American journal of physiology. Cell physiology* **278**, C235-256 (2000).

4 Nilsson, H. & Aalkjaer, C. Vasomotion: mechanisms and physiological importance. *Molecular interventions* **3**, 79-89, 51, (2003).

5 Girouard, H. *et al.* Astrocytic endfoot Ca2+ and BK channels determine both arteriolar dilation and constriction. *P Natl Acad Sci USA* **107**, 3811-3816, (2010).