Modulating the Functional Synchrony in the Primary Visual Cortex of the Human Brain

G. Xu[1], Y. Xu[1], G. Wu[1], S-J. Li[1]

[1]Department of Biophysics, Medical College of Wisconsin, Milwaukee, Wisconsin, United States

Introduction: Previous studies have shown that the spontaneous low frequency oscillations in blood oxygenation-level dependent (BOLD) weighted fMRI signals are functionally relevant [1]. However, the fMRI low frequency signal oscillations in sensory cortex upon different stimuli conditions have not been well characterized. A recent study demonstrated that a large BOLD signal decrease in the human visual cortex was observed after a subject simply closed their eyes [2]. This finding led to a hypothesis that the functionally related spontaneous low frequency (SLF) in those voxels would also change upon similar task paradigms. In this study, we have designed three different visual stimulus paradigms to test our hypothesis. We demonstrate that the functional synchronies of these oscillations are significantly different in visual cortex when subjects perform different tasks.

Method & Materials: Four male cognitively healthy volunteers (age 27±3 years) participated in this study. Informed consents were obtained from all subjects for this IRB-approved study. fMRI data were acquired on a Bruker BioSpec 3.0T scanner using a single-shot gradient-echo EPI sequence (TE = 27.2 ms, TR = 2 s, 64×64 in-plane resolution, FOV = 24 cm, 125 kHz acquisition bandwidth, 6 mm slice thickness, 20 axial slices). Three different visual tasks were employed: Task A) viewing flickering square checkerboard, Task B) visual fixation with a white screen and a red cross, and Task C) resting with eye closed in dimmed light environment. Scan 1 lasted for 10 min with the first 6 min continuously performing task A and the last 4 min performing alternative block design with 30 s task A and 30 s task B; scan 2 also lasted for 10 min with the first 6 min continuously conducting task B and last 4 min performing task B and task A alternatively; scan 3 lasted for 6 min with task C, as shown in the left panel in Fig. 1. A set of high-resolution anatomical images was acquired for image registration. **Data Analysis:** The voxel time courses in the last 4 min of both scans 1 and 2 were employed to generate activation maps using the cross-correlation method in a block-design paradigm (*p* <0.01). The voxel time courses in each of the first 6-min scans were employed to quantify the functional synchrony by using the cross-correlation of the spontaneous low frequency fluctuation (COSLOF) and the phase delay index (PDI) method described previously [3]. Only those activated voxels in the visual cortex (BA17, 18 & 19) were selected for the calculation of COSLOF and PDI. The activation map generated from scan 2 was used for the synchrony calculation of scan 3.

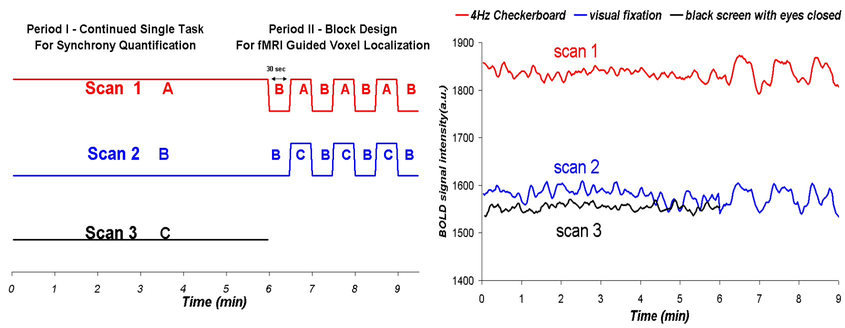

Fig. 1: Task paradigms (left) and averaged voxel time courses (VTC) (right) from activated voxels in the primary visual cortex. Those voxels activated in task B were employed to generate the averaged VTC for task C.

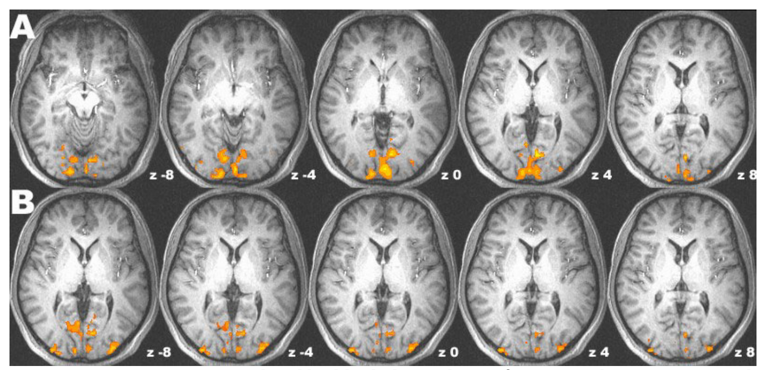

Fig. 2: Activation maps stimulated by block design by performing task A (Fig. 2A) and task B (Fig. 2B).

Results: Figure 1 (right panel) showed that the signal intensities of averaged voxel time courses acquired in the first 6-min period are different when performing the three tasks. Among the three tasks, the signal intensity is the lowest when subjects were closing their eyes (task C), highest for viewing the flickering checkerboard (task A), and in between for the visual fixation (task B). Figure 2A shows the task A-activated areas in the primary visual cortex and Fig. 2B shows the task B-activated areas. The PDI values, a quantitative measurement of the functional synchrony, are significantly different when performing these tasks (paired Student *t*-test with one tail, $p<0.006$ for task A vs. task B and $p<0.048$ for task A vs. task C). A similar result can be seen for the COSLOF index as shown in Table 1.

Discussion and Conclusion: We demonstrated that in the primary visual cortex the quantitative assessment of functional synchrony with both PDI and the COSLOF index revealed that the spontaneous low frequency oscillation can be modulated under different tasks. According to the definition of PDI, the lower the PDI value, the less the phase shifts between the voxel time courses with the higher cross-correlation coefficients, which indicates higher functional synchrony between voxel time courses. These changes of functional synchrony under different tasks measured in this study are consistent with those BOLD signal changes obtained from the conventional fMRI studies [2]. For example, task A has both the highest BOLD signal and the highest functional synchrony, whereas task C has the lowest of both. These results suggest that functional synchrony is relevant to neural activities and could be employed to define a regional default mode of brain function [4].

Index for functional synchrony	Task A	Task B	Task C
COSLOF	0.31±0.06	0.27±0.04	0.20±0.02
PDI	35.45±5.55	39.61±5.00	48.29±3.04

Table 1. The quantitatively measured indices for evaluating the changes in functional synchrony in the primary visual cortex when performing different visual tasks.

References:
1. Biswal B., et al. MRM, 34(4):537-541, 1995.
2. Uludag K., et al. NeuroImage, 23:148-155, 2004.
3. Yin Xu, et al. ISMRM 12:498, 2004.
4. Raichle M.E., et al. PNAS, 98(2):676-682, 2001.

Acknowledgments: This work is supported by NIH Grants AG20279, EB02014, and RR00058.