Phase fMRI at 7 Tesla

K. Zhong[1], J. Leupold[1], J. Stadler[2], C. Tempelmann[3], and O. Speck[1,4]

[1]Dept. of Diagnostic Radiology, University Hospital Freiburg, Freiburg, Germany, [2]Leibniz Institute for Neurobiology, Magdeburg, Germany, [3]Department of Neurology II, Otto-von-Guericke University, Magdeburg, Germany, [4]Dept. of Biomedical Magnetic Resonance, Otto-von-Guericke University, Magdeburg, Germany

Introduction: Conventional fMRI studies are based on signal magnitude changes from T_2/T_2^* increase due to blood susceptibility variations. On the other hand, blood susceptibility changes also induce frequency shifts that are largely ignored in the fMRI data analysis. Studies have suggested that voxel phase time course might show task related changes (1,2) and recently a new GLM model has also been proposed for fMRI which uses both the magnitude and phase of complex data (3,4). It was shown that an unrestricted phase model was mathematically equivalent to the magnitude only model. However, a phase only model would interpret data disregard of their SNR and also predict more activation regions outside loci of interest.

Task related phase changes are caused by counter-acting effects of CBV increase and blood oxygenation increase which are field dependent. Therefore, this study investigates how the phase effects from neuronal activation vary with field strength. The fMRI phase changes at different field strengths ranging from 1.5 to 7 Tesla were measured and the possibility for using phase fMRI as a sensitive probe for BOLD effects at high field was evaluated.

Experimental: Experiments were carried out on three scanners: Siemens Sonata (1.5 T), Siemens Trio (3 T) and Siemens MAGNETOM 7 T. Eight channel phase arrays were used to acquire all images at different field strengths. A gradient echo EPI sequence was used to acquire both the magnitude and phase images. Image matrix size was 128x96x11 with 2 mm in-plane resolution. The echo times for different field strengths were adjusted to approx. T_2^* values: 60 ms (1.5 T), 32 ms (3 T) and 24 ms (7 T). Two volunteers were scanned at all field strength. A finger tapping task was used with 30s OFF/30s ON and a total acquisition time of 300 s. MATLAB and SPM5 were used for data processing. Statistic maps were obtained from the magnitude images based on which ROIs in the active regions were selected. The ROIs were applied to both magnitude and phase images to extract their corresponding time course. If necessary, the phase images were unwrapped prior to the ROI extraction. For phase time course, linear correction was applied to remove the global frequency drift during GE-EPI acquisitions. Finally, magnitude time course were normalized to their mean values and phase time courses were subtracted by their mean values.

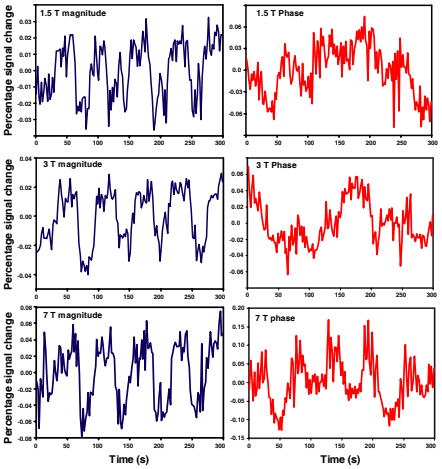

Figure 1: Time courses (TCs) for both magnitude (blue) and phase (red) at different field strengths. The differences in the activation level in the magnitude TC were due to different ROI selections in the activated area. TCs for phase images showed no significant task related changes at 1.5 and 3 T. Phase TC at 7 T showed strong high frequency modulation that might be due to subject respiration. The 7 T phase TC also showed clear task related signal change.

Result and Discussion: Time courses (TCs) of magnitude (blue) and phase (red) at different field strengths are shown in Figure 1. All magnitude TCs showed task related changes. TCs for phase images showed no significant task related changes at 1.5 and 3 T. In comparison, the phase TC at 7 T showed clear task related signal changes. In addition, the 7 T phase TC also showed strong periodic signal modulation around 4-6 s that is likely due to respiration. After applying a low-pass filter to remove this physiological noise component, the 7 T phase TC showed very good correlation with the magnitude TC (Fig.2). The average phase change was estimated to be approx. 0.12. The phase (φ) induced by changes in blood volume (v) and oxygenation level (Y) (Fig. 3) is given as $\varphi = 2\pi \cdot v \cdot (1-Y) \cdot \Delta\chi \cdot B_0 \cdot TE$, where $\Delta\chi$ is the blood susceptibility for 0.4 hematocrit (0.08 ppm), B_0 the Larmor frequency and TE the echo time. If one assumes an oxygenation change from 50% to 70% with a CBV increase of 50% from 4%, then the phase change would be around 0.15. Therefore, the observed 7 T phase change of 0.12 agrees well with the theoretical estimation. Since the phase change is proportional to the Larmor frequency and the echo time, the phase change at 1.5 and 3 T can be estimated using the 7 T results and is shown in Figure 4 (blue) along with the estimated noise level at each field strength (red) using ROIs from cortex without activation. 7 T phase data had the highest CNR while the 1.5 T CNR was the lowest. This is consistent with Fig.1 where 7 T phase TC showed clear activation while 1.5 T data showed mostly noise. On the other hand, the 3 T data had comparable CNR as the 7 T data but showed little activation in Fig.1. Therefore, more experiments are required to explain the fMRI phase effect at 3 T.

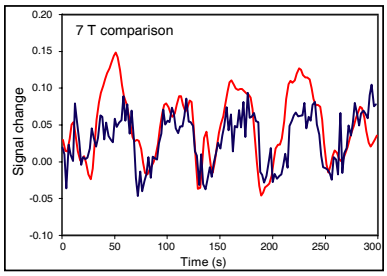

Figure 2: Comparison of the magnitude (blue) and phase (red) TC at 7 T. Both curves showed good correlation. The phase TC was processed with a low-past filter to remove the respiration noise and the direction was reversed for better visualization.

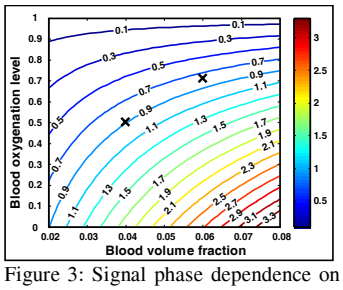

Figure 3: Signal phase dependence on blood volume and oxygenation level at 7 T (TE = 24 ms). Estimated phase change during neuronal activation (indicated by the black cross and described in text) is around 0.15, and is consistent with the result in Fig. 2 (~ 0.12).

Conclusion: The important observations in this study were the strong phase changes and clear physiological phase modulation at 7 T which were not present in the 1.5 and 3 T data. The signal difference can be explained by changes of blood volume and oxygenation. The physiological modulation presented at high field may also be used for physiologic noise removal in fMRI analysis. In addition, the phase information may be utilized to further improve BOLD detection sensitivity at high field.

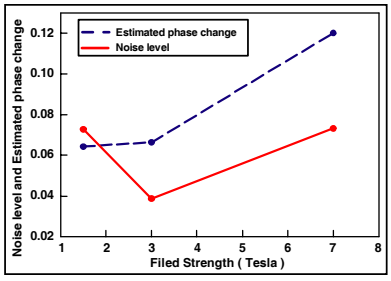

Figure 4: Comparison of the estimated phase changes with their corresponding noise levels for different field strengths. The estimated CNR values are 0.9 (1.5 T), 1.6 (3 T) and 1.7 (7 T).

References:

1. Hoogenrad, F.G. *et al. MRM* 39:97-107 (1998)
2. Menon, R.S. *et al. MRM* 47:1-9 (2002)
3. Rowe D.B. et al. *NeuroImage* 23:1078-92 (2004)
4. Rowe D.B. *NeuroImage* 25:1310-24 (2005)