Single-Shot Whole Brain Echo Volume Imaging for Temporally Resolved Physiological Signals in fMRI

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Introduction: Single-shot Echo Volume Imaging enables whole-head fMRI data acquisition with sample rates of up to 10 frames per second.[1] A motivation for fast sampling is that the dominant physiological noise sources, such as respiration and cardiac pulsation, will not be temporally aliased into the frequency band of the activation and can be isolated directly. Here we present 64x64x56 matrix whole-head 3T fMRI data sampled at 8 frames per second and 3.4mm isotropic resolution with the k_z phase encoding direction accelerated by a total of 21 fold to reduce distortions in this "slow" phase encoding direction 21 fold. We analyze the spectral composition of BOLD and physiological signals to show that full Nyquist the cardiac frequency is helpful in mitigating their effect on the estimation of the fMRI activation.

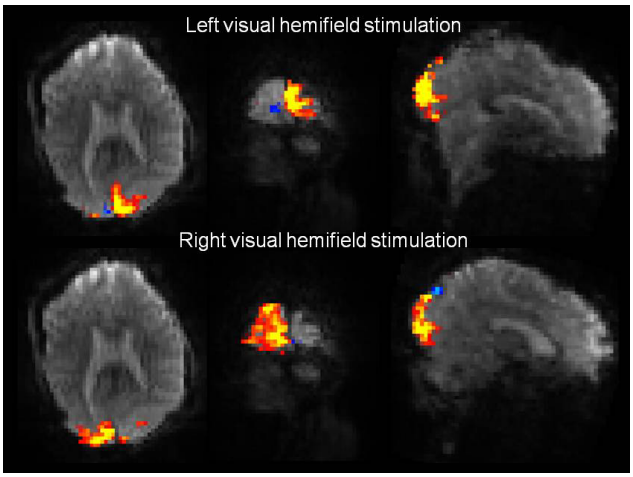

Figure 1: Results of visual hemifield experiment in neurological orientation. The activation threshold was set at z > 8.

Methods: We acquired single-shot EVI data with a matrix size of 64x64x56, 3.4 mm isotropic nominal spatial resolution, 4x4 fold undersampling, 6/8 partial Fourier, TR/TE/flip=120ms/36ms/21° and a readout bandwidth of 3005Hz/px on a Siemens 3T TIM Trio scanner using the product 32-channel receive array coil. The readout direction was head to foot (HF), the primary phase encoding direction anterior to posterior (AP) and the secondary phase encoding direction right to left (RL). The time between phase encode lines in the fast and slow PE directions were 0.46ms and 5.52ms. Total readout duration was 77.3ms. Given the 4x4 accleration, the effective echo-spacings (which determine image distortion) were 0.115ms in AP (BW_{AP}=180Hz/px) and 1.38 ms in RL (BW_{RL}=13Hz/px). Quadratic RF spoiling (increment 117°) [2] was used. The images were reconstructed offline using GRAPPA and motion corrected using AFNI [3]. No spatial smoothing was applied.

A block-design experiment was performed with a visual stimulus consisting of a random flickering spatial noise pattern shown in either the left or right visual hemifield for a duration of 16 seconds followed by a blank gray screen (10s). To ensure eye fixation, the subject was asked to monitor a small red fixation dot and respond when the dot intensity changed (approximately 2 second intervals). The difficulty was adjusted to 80% subject performance. Eight 2-minute runs of this experiment were recorded together with pulse oximetry and pneumatic belt data. The fMRI analysis was performed using a simple GLM. The BOLD response was modeled using the HRF model from the SPM package. The first derivatives of the BOLD response were modeled as well as a constant, linear trend, motion parameters and the respiratory belt terms. In order to model cardiac effects the temporal shifts between the pulse-oximeter data and each voxel was determined using cross-correlation, and the pulse oximeter data was then included with the appropriate time-shift for each voxel in the design matrix. No temporal pre-whitening was used at this time, thus leading to overestimated significance values. Furthermore no multiple-comparisons correction was applied. The runs were combined using a fixed effects model. For the calculation of the Power Spectral Densities (PSD) the data were second-order detrended and the spectra were then estimated using the Welch algorithm in MATLAB with a resolution of 256 points. The results in Figure 1 and Figure 2 are overlaid on a 10-TR average EVI image acquired with a TR of 5s for clearer anatomical visualization.

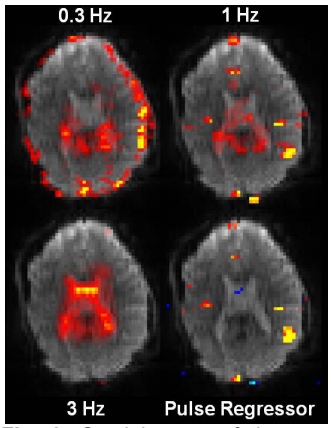

Fig. 2: Spatial maps of the power spectral densities at the respiratory (0.3Hz), cardiac (1Hz), and 3rd harmonic of cardiac (3Hz), as well as the pulse oximetry regressor map thresholded at z>5.

Results & Discussion: The GLM analysis shows the expected lateralized activation in the occipital lobe for the stimulus paradigm, such that the BOLD response is located contralateral to the visual hemifield stimulated (Figure 1). The whole-head PSD maps (Figure 2) showed respiratory frequency power in the CSF/cortex interface, which appears to be most pronounced in the RL direction. Due to the low BW (13 Hz/px) in this direction, most of the B_0 shifts induced by thoracic air volume manifest as RL translations, which in turn are removed by the motion correction but the resampling likely introduces the observed amplitude variations at the respiratory frequency band. The cardiac frequency band exhibits a localized spatial distribution with peaks in blood vessels. Curiously the ventricles show strong higher-harmonics of the cardiac frequencies, in some locations even missing the fundamental, which makes them the anatomical structure with the highest frequency noise observed in the brain. Also shown in Figure 2 is the t-statistic for the aligned pulse oximetry regressor. It shows high significance for blood vessels, matching the 1Hz spectral density. Virtually all significant voxels show a delay of 4TR (480 ms) between pulse oximeter and voxel pulse, as determined by cross-correlation prior to the GLM. Figure 3 shows the agreement between the power spectral density of the physiological monitoring data and voxels from selected tissue types, further demonstrating that the physiological signals are temporally resolved in the EVI data.

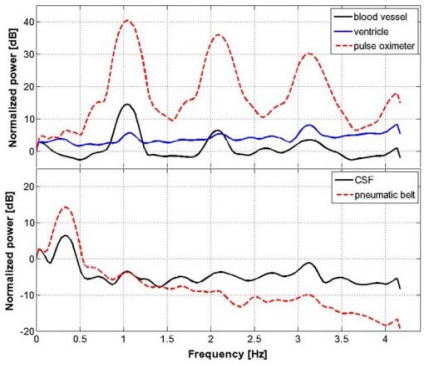

Figure 3: Normalized power spectral density plots of physiological monitoring data and tissues showing prominent spectral features.

Conclusion: High quality whole brain single-shot EVI is possible at useful spatial-temporal resolutions with acceptable distortion levels. The temporal resolution allows an unaliased spectral analysis and mitigation of physiological noise in the volumetric data.

References [1] Witzel, ISMRM2008:2367 [2] Dyun, MRM:37(4):559-68, [3] Cox, Comput Biomed Res 29:162-173. **Acknowledgements:** Supported by NCRR P41 RR14075 and NIBIB R01EB006847.