The Effect of parallel imaging on the sensitivity of BOLD signal to physiological noise

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Introduction: With the development of phased-array detectors, parallel imaging techniques have been widely used for BOLD fMRI studies, driven by the advantages of enhanced imaging speed and reduced susceptibility artefacts. However, the sensitivity to physiological noises of the reconstructed BOLD MR images is also altered by the employed parallel imaging strategies. This has become an very important issue for conducting BOLD fMRI and resting-state connectivity mapping at higher field strength, owing to the significantly amplified sensitivity of BOLD signal to physiological noise. To gain further insight into this, in this study, we mapped and compared the physiological noise sensitivity of BOLD fMRI data acquired with and without employing parallel imaging at two different spatial resolutions.

Materials and Method: Seven normal adult volunteers (aged of 37±4 years old) participated in the study. All MRI measurements were performed by using a Siemens 3T clinical MRI scanner equipped with a 32 channel phased-array coil for brain imaging. To map the physiological noise sensitivity of the BOLD fMRI data, T2*-weighted images were acquired as a function of the flip angle for RF excitation pulse. The data acquisition protocol was based on a single-shot gradient-recalled echo (GRE) 2D echo-planar imaging (EPI) technique and included the following scan series: 1) fast anatomical localizer; 2) whole-brain 3D shimming; 3) whole brain T1-weighted anatomical scan at 1 mm isotropic resolution, 4) measurement of thermal noise by switching off the transmitter while acquiring a set of BOLD fMRI data using the parameter specified below. 4) Fives sets of resting-state BOLD fMRI data sets without parallel imaging acceleration (IPAT=1) at five different flip angles (α=90 °, 80 °, 60 °, 40 °, 20°); 5) Fives sets of BOLD fMRI data sets with parallel imaging acceleration (GRAPPA, IPAT=2) at five different flip angles specified above. To facilitate the comparison, the acquisition parameters except for those associated with parallel imaging were kept the same for all the BOLD fMRI data. These include TE/TR=35/2000ms, in-plane spatial resolution=2x2 mm^2, 22 oblique axial slices of 2 mm thick, 180 timeframes per series. The scan time for the entire protocol lasted for about 90 minutes. Each subject repeated the above protocol in a separate session by using a lower spatial resolution of 3 mm for the BOLD data acquisition. The post-processing of the data conducted off-line by using the AFNI software and Matlab. The main post-processing steps included the followings: 1) motion correction by 3D rigid-body image registration, 2) voxel-wise computation of temporal SNR_t (mean signal intensity/temporal signal standard deviation), 3) extraction of the intrinsic SNR and sensitivity to physiological noise (λ) from the SNR_t dependence on the RF flip angles by non-linear curve fitting of the theoretical model [1] to the measured BOLD image data.

Results: As shown in Figure 1, the intrinsic SNR and sensitivity to physiological noise in the brain are not evenly distributed. GRE signals in the cortical gray matter has significantly higher SNR as well as noise sensitivity. The noise sensitivity in white matter is about half of that in gray matter. With the use of parallel imaging reconstruction, the noise sensitivity is significantly increased, while the intrinsic SNR is reduced for both gray and white matter. Reducing the image resolution form 2 mm to 3 mm, The intrinsic SNR is approximately doubled, but the SNR improvement is far less than what is expected from the volumetric increase of the voxels. This is likely due to the increased noise sensitivity of the GRE signal at lower spatial resolution with larger volume contributing both coherent and incoherent physiological noises. Details on how the intrinsic SNR and noise sensitivity are altered by the use of parallel imaging acquisition and different spatial resolution are summarized in Table 1, which based on multiple ROI analysis of the SNR and λ maps from all the participants.

Discussion: Compared with earlier studies [1,2], we mapped the noise sensitivity for the cases with and without the use of parallel imaging at two different spatial resolutions. The results give us some interesting insights into how the noise sensitivity and intrinsic SNR of BOLD fMRI data are affected by the choice of acquisition methods and spatial resolution. Using higher spatial resolution reduces the signal strength and the relative sensitivity to physiological noise. This can be of SNR advantage particularly for time series fMRI data acquired at higher magnetic field [2]. It is apparently important for optimal functional brain mapping to use the appropriate parallel imaging strategy and spatial resolution for a given hardware setting. Moreover, a number of effective approaches have been proposed in the literature to reduce the sensitivity of BOLD signal to the remaining physiological noise in the brain by taking advantage of the auxiliary recordings of the body physiological signals and the coherence characteristics of the noise [3,4].

References: [1] Kruger G. *Magn Reson Med* **46**:631 (2001); [2] Triantafyllou C. *Neuroimage* **26**:243 (2005); [3] De Zwart J. et al. *Magn Reson Med* **59**:939 (2008); [4] Bianciardi M.*, Neuroimage,* **44**:448 (2009).

Table 1: SNR and λ

Imaging Resolution	Brain Tissue	IPAT=2		IPAT=1	
		SNR±std	λ±std	SNR±std	λ±std
2mm	gray	75±7	1.3±0.5	86±8	1.0±0.4
	white	44±3	0.7±0.2	58±4	0.6±0.1
3mm	gray	158±10	1.7±0.6	163±10	1.5±1.0
	white	116±8	1.0±0.2	128±7	0.8±0.2