Length-scale dependent effects of noise reduction in phase and magnitude fMRI time-series

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Introduction

fMRI analyses are primarily based on the magnitude information in gradient-echo echo-planar images (GE-EPI) but a growing number of studies also included the phase information. An issue relates to physiologic large-scale phase effects that are more prominent in phase than magnitude data [1]. Recently it was shown at 7T that temporal phase noise can be predicted from the inverse of the magnitude temporal stability (1/tSNR) after RETROICOR based removal of physiological fluctuations, but with a different TE-related mechanism for the phase signal for the local scale effects [2]. In the present work we explored the phase stability at different length scales at 3T and found that further improvements in temporal stability can be achieved by alternative noise-reduction methods that take into account the differential origin of noise effects in phase and magnitude data.

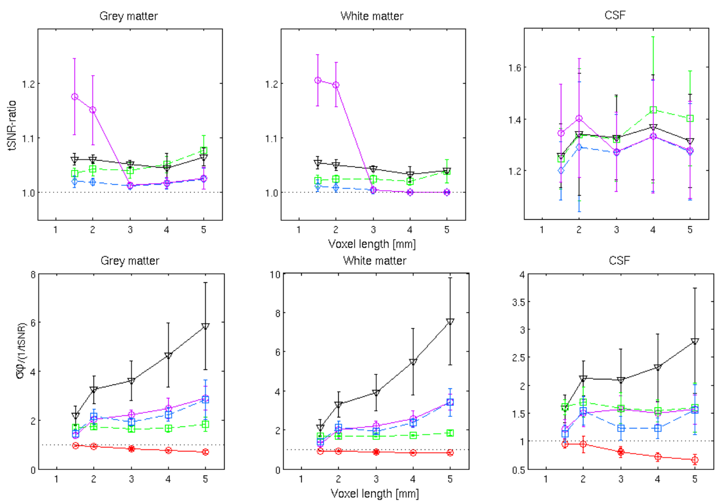

Fig: Relative temporal stability for various fMRI voxel sizes (average across 7 subjects, and 95% confidence interval). **Magnitude data (above):** ratio of corrected tSNR over uncorrected tSNR. Noise reduction by RETROICOR, (black triangles, solid line), NVR (green squares, dashed line), zeroth order DORK0 correction (blue diamonds, dashed line) or after a first order DORK1 correction (magenta circles, solid line). The dotted line at a ratio value of 1 indicates the cut-off for equal temporal stability, values located above this line have a higher stability. **Phase data (below):** ratio of the phase standard deviation over the inverse of the magnitude tSNR in the uncorrected magnitude data. Methods as above except k-space homodyne filtering with a Hamming window (blue squares, dashed line), or spline window (red circles, solid line). The dotted line at a ratio value of 1 indicates the cut-off for equal temporal stability, values located below this line have improved stability.

Materials and methods

Magnitude and phase stabilities, obtained after spatial [3] and temporal unwrapping, were evaluated in the CSF, gray and white matter at 3T (Siemens Medical Systems) in 7 healthy subjects (26±7y) that volunteered to participate in the study, approved by the local ethics review board. They were scanned while at rest with eyes closed in a dimly lit room with five different fMRI protocols and the in-plane isotropic voxel length was varied between 1.5 and 5 mm (gradient echo EPI, 100 volumes, TR=2s, TE=30 ms, slice thickness: 2.5 mm and a 50% gap between slices). ECG (400 Hz sampling rate) and respiration belt (50 Hz) data were monitored in synchrony with each fMRI protocol with equipment provided by the scanner manufacturer. Tissue classification was obtained by segmentation of anatomical T1-weighted images in SPM2, coregistered to the EPI scans. Noise reduction was achieved for both data sets by A) RETROICOR [4]; B) NVR, single nuisance variable regressor obtained from the phase evolution of the central k-space point; C) DORK0, 0^{th} order 'dynamic off-resonance in k-space' correction [5]; D) DORK1, 1^{st} order DORK; while for the phase data two additional methods for gradient background removal were performed: E) spatial high pass filtering achieved by a homodyne k-space Hamming (FWHM: 3.5 pixels) filter; E) cubic spline filter weighted by a 2D Gaussian window yielding an approximation of the magnitude k-space values with tolerance 100. Linear detrending was applied to the magnitude and phase time series prior to a pixel wise calculation of the temporal stability tSNR for the magnitude images and σ_{φ} for the phase images.

Results and discussion

For the magnitude data,RETROICOR yielded the most robust noise reducing effect across voxel sizes, while for the smallest voxels, dominated by instrumental noise, additional improvements were achieved by the DORK1 correction. In the phase data noise reduction depended on the voxelsize and the post-processing methods. RETROICOR correction improved the phase stability between 4-30%, less than at 7T [2]. Increased stability could be achieved by DORK1 and NVR, although in presence of partial volume effects and high physiological noise components in the larger voxel sizes improvements were less substantial. Interestingly, the dynamically updated k-space spline filtering decreased phase fluctuations to below expected values based on the magnitude data. The method was particularly successful in large voxels. These results hold promise for future fMRI applications and may even suggest that the two data sets are pre-processed differently in order to take account of the length-scale dependent effects of noise manifestations in phase and magnitude data.

[1] Petridou et al., 2009 MRI 27:1046; [2] Hagberg etal., 2008 MRI 26:1026; [3] Jenkinson 2003 MRM 49:193; [4] Glover et al., 2000 MRM 44:162; [5] Pfeuffer et al., 2002 MRM47:344