The effect of physiological noise on fMRI phase time series

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Introduction

MRI is a phase sensitive detection system and both magnitude and phase time-series are obtained in an fMRI study. Recently, the possibility to use both image sets for the statistical evaluation of fMRI data has been proposed, with the prospective of increasing both statistical power and spatial specificity of the activation maps (1-3). In order to fully take advantage of the additional information in phase images, knowledge regarding available phase stability is needed. Here we propose and investigate three models for the phase stability at 3T, and each model is dependent on the relation between the effect of physiological noise on magnitude and phase variations.

Theory

In model I, no effect of physiologic noise on phase images is assumed and the temporal standard deviation of the phase, tSD_φ, is given by the inverse of the magnitude signal-to-noise ratio at a single time point *SNRo* (4). In model II, common manifestations in magnitude and phase images are assumed. For the magnitude data, the Krüger and Glover model for the relation between temporal stability *tSNR* and *SNRo* holds (5). For high levels of temporal stability, the validity of the Gudbjartsson and Patz relationship may still hold, but *SNRo* has to be substituted by *tSNR* and the λ factor is the same in phase as in magnitude images. Finally in model III, we assumed that physiological processes are different in phase than in magnitude images, but that they still adhere to the general form of model II, with $\lambda \neq \lambda_\varphi$:

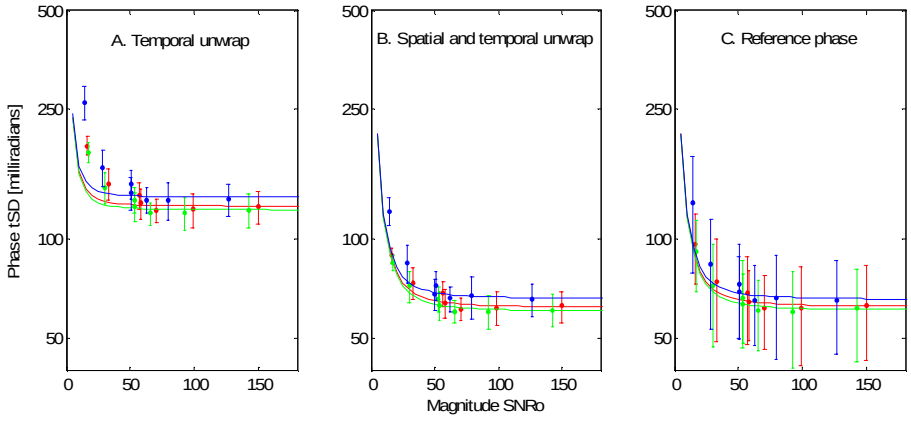
$$tSD_\varphi^{\ I} = \frac{1}{SNRo} \qquad tSD_\varphi^{\ II} = \frac{1}{tSNR} = \frac{\sqrt{1+\lambda^2 \cdot SNRo^2}}{SNRo} \qquad tSD_\varphi^{\ III} = \frac{\sqrt{1+\lambda_\varphi^{\ 2} \cdot SNRo^2}}{SNRo}.$$

Materials and Methods

Magnitude and phase stabilities were evaluated in the CSF, grey 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 with seven different fMRI protocols while at rest with eyes closed in the dimly lit magnet room. Magnitude *SNRo* was varied by varying the in-plane isotropic voxel length between 1.5 and 5 mm and, in the case of the lowest *SNRo*, the repetition time. Common parameters for all protocols were gradient echo EPI, 100 volumes, TR=2s or 0.18s , TE=30 ms, slice thickness: 2.5 mm and a 50% gap between slices. Motion during scan was controlled post-hoc and one subject was excluded from further analysis because of translation >0.5 mm and rotation> 0.5º. Tissue classification was obtained by segmentation of anatomical T1-weighted images in SPM2 coregistered to the EPI scans. The phase data was post-processed by three different methods: 1) temporal unwrap only, 2) spatial unwrap (6) and temporal unwrap, 3) the reference phase method (7) and temporal unwrap. Linear detrending was applied to the magnitude and phase time series prior to a pixel wise calculation of *tSNR* for the magnitude images and tSD_φ for the phase images. Weighted (by the *SNRo*) linear least-squares curve-fitting of the average magnitude *tSNR* and the phase tSD_φ as functions of *SNRo* were evaluated. In this way, the magnitude λ factor could be determined, and thus a prediction for the phase values according to model II could be obtained, while direct fits of the phase data yielded the unknown parameter λ_φ in model III.

Results and Discussion

The temporal SNR was evaluated in magnitude images and was found to be satisfactory in view of 3T literature data, corresponding to *tSNR* limits of 105, 184 and 45 in grey and white matter, CSF, respectively. Predictions from magnitude data regarding phase stability according to model II would thus predict phase stability values in terms of tSD^{II}_φ of 10, 5, and 22 milliradians. These limiting values were not achieved, instead, for all three investigated post-processing methods we found support for validity of model III with $\lambda_\varphi >> \lambda$ (Table). The spatio-temporal unwrap and reference phase methods gave the smallest λ_φ values, while the best inter-individual reproducibility was obtained by spatio-temporal unwrap (Figure). Although spatio-temporal unwrap (B) and the reference phase method (C) improved phase stability by a factor of two with respect to temporal unwrap (A) the limiting values obtained from the magnitude images were never achieved, supporting the notion that manifestations of physiologic noise is more prominent in phase than magnitude images. These data prompt for improved phase post-processing methods in order to fully exploit their potential in statistical analysis of fMRI images.



Tissue	Magnitude tSNR λ	Temporal unwrap, λ_φ	Spatio temporal, λ_φ	Reference phase λ_φ
Grey matter	0.0095	0.1264	0.0621	0.0625
White matter	0.0054	0.1232	0.0603	0.0608
CSF	0.0221	0.1348	0.0660	0.0657

References

(1) Logan BR, Rowe DB. Neuroimage 2004;23:1078 (2) Menon R. MRM 2002; 47:1 (3) Lee J, Shahram M, et al.,. MRM 2007;57:905 (4) Gudbjartsson H, Patz S. MRM 1995; 34:910 (5) Krüger G, Glover GH. MRM 2001;46:631 (6) Jenkinson M. MRM 2003;49:193 (7) Tomasi DG, Caparelli EG. JCBF 2007; 27:33-42