Examination of Non-Physiological Sources of 1/f-like Noise in EPI Power Spectra

D. A. Soltysik[1], V. Roopchansingh[1], J. S. Hyde[1]

[1]Biophysics, Medical College of Wisconsin, Milwaukee, WI, United States

Introduction

Understanding the noise structure of echo-planar imaging (EPI) time series is important for determining the significance of test statistics in functional MRI (fMRI) or low frequency correlations in functional connectivity studies. Weisskoff et al.[1] revealed the existence of a 1/f-like shape to the power spectrum of EPI data that is more pronounced in gray matter compared to white matter. Biswal et al.[2] found evidence for functional connectivity between separate brain regions using low frequency fluctuations in resting state EPI data. Hyde et al.[3] proposed a model for fMRI contrast-to-noise ratio (CNR) in which low frequency noise was dominated by spontaneous BOLD fluctuations. However, low frequency noise has been found in white matter,[1] phantoms,[4] and cadaver brains,[5] suggesting that other sources of low frequency noise exist. Smith et al.[5] argued that dynamic instabilities in the static magnetic field may lead to partial voluming effects more apparent along regions of large spatial gradients, resulting in low frequency noise. The goal of this study is to characterize the alternate sources, apart from physiological fluctuations, of this low frequency noise. A further quantization of the 1/f-like shape has been made by fitting EPI power spectra to $1/f^{\alpha}$ curves on a voxelwise basis. Low frequency content can be assessed using α values, which are seen to vary across tissue type, phantom type, TR, and voxel size.

Methods

One male subject (aged 31) and two phantoms were scanned. The phantoms included a gridded water phantom filled with 0.005 M $CuSO_4$, 0.0938 M NaCl and a spherical agar phantom filled with 0.030 M $NiCl_2$. The gridded water phantom had interlocking plastic panels creating 1 cm^3 volumes of water. All experiments were performed on a GE 3T Excite scanner using an 8-channel array RF head coil. T_2^*-weighted EPI sequences were used to obtain time-series data. Several TRs and voxel sizes were used. The scan time in each case was 260 s.

Analysis

Low frequency effects were examined by finding the power spectra for voxel time series for voxels included in a phantom mask or a brain mask. The log of the power spectrum vs. the log of the frequency was fitted to a straight line, $\log(P(f)) = C - \alpha \cdot \log(f)$ (Fig. 1), for each of these voxels. Maps of α were created for slices of the human brain and the phantoms.

Results

An α map for one slice of human brain data acquired at TR = 2000 ms is shown in Fig. 2a. Generally, white matter voxels contain α values near 0, while gray matter voxels have higher α values. However, no correlation was found between intensity of the voxel on the first shot and α. Decreasing the TR was seen to reduce the magnitude of α values across much of the brain.

Phantom experiments were analyzed to further understand low frequency effects. α maps for data acquired at TR = 2000 ms for both phantoms are shown in Figs. 2b,c. The gridded water phantom shows a distribution of α values from about 0 to 2, while the agar phantom shows a distribution of α values from about 0 to 1.3. After allowing the gridded phantom to rest in the scanner overnight, it was scanned again with identical parameters. This resulted in much less low frequency noise (Fig. 2d). The agar phantom and human brain were rescanned with smaller voxel sizes, resulting in remarkably different α maps (Figs. 2e,f).

Discussion

It was hypothesized that the strong low frequency signals seen in the gridded water phantom (Fig. 2b) were caused by the turbulent flow of water. After the phantom was allowed to rest overnight and rescanned, much of the low frequency noise disappeared (Fig. 2d). Low frequency noise was also seen in the agar phantom, for which there can be no flow (Fig. 2c). It was hypothesized that scanner instabilities and physical inhomogeneities in the phantom led to varying field inhomogeneities, resulting in low frequency noise. Field inhomogeneities led to intravoxel dephasing, which increases with voxel size. As the voxel size was decreased, the low frequency noise of the agar phantom virtually disappeared (Fig. 2e), but some low frequency noise remained along gray matter in the human brain (Fig. 2f). It is believed that these remaining low frequency signals in the brain may result from the spontaneous BOLD fluctuations reported elsewhere.[2,3] In conclusion, it is believed that small voxel sizes are desired to avoid 1/f-like noise from non-physiological sources when performing fMRI experiments or functional connectivity studies.

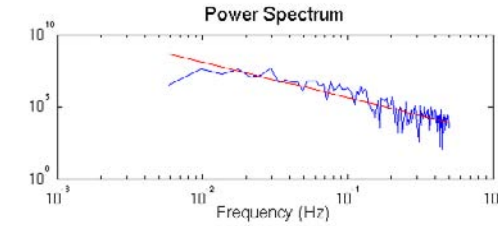

Fig. 1. Example of log-log plot of power spectrum fitted to a line.

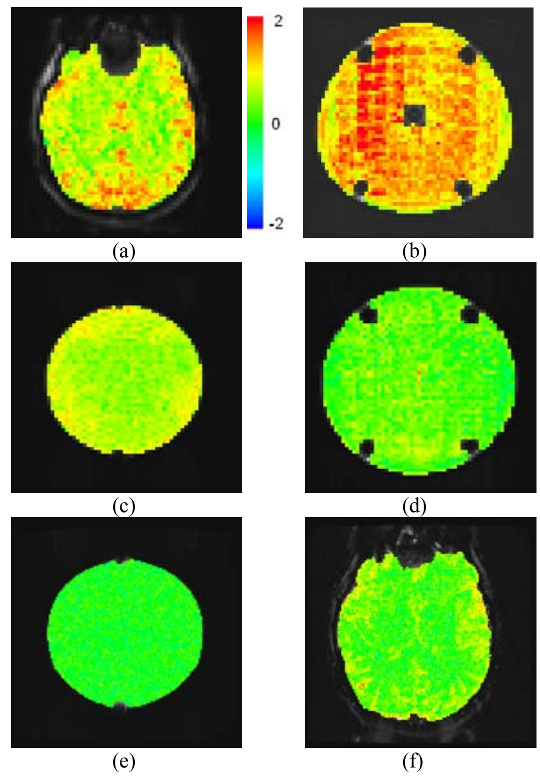

Fig. 2. Maps of α for TR = 2000 ms for (a) human brain acquired with 3.125×3.125×6 mm^3 voxels, (b) gridded phantom acquired with 3.125×3.125×6 mm^3 voxels, (c) agar phantom acquired with 4×4×5 mm^3 voxels, (d) gridded phantom acquired with 3.125×3.125×6 mm^3 voxels, after resting in scanner overnight, (e), agar phantom acquired with 2×2×3 mm^3 voxels, and (f) human brain acquired with 1.562×1.562×2 mm^3 voxels.

References

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