Simple Model to Describe Weisskoff EPI Temporal Stability Test - Analogy with Physiological Noise Model in Oxygenation-Sensitive fMRI.

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Introduction: Simple measurement of MRI scanner temporal stability, the crucial factor in fMRI, was introduced by Weisskoff (1). In this method the EPI time series fluctuations described as relative deviations (Fn) are measured on the phantom and plot as a function of square ROI length. As ROI length increases the deviation of this plot from theoretical value (WP0: Fn,t=1/(n*SNR), where SNR is an image signal-to-noise ratio) characterized MRI scanner related instabilities. Here we introduce an analytical model to describe Weisskoff plot (WP: Fn plot versus N) and we recognize and draw an analogy with physiological model in oxygenation-sensitive MRI (2).

Theory: We have assumed that MRI noise variance measured on the phantom (σ^2) is a superposition of thermal and scanner related noise contributions ($\sigma^2=\sigma_0^2+\sigma_S^2$). We have also assumed that scanner related noise is proportional to the MRI signal ($\sigma_S=\lambda S$) similar to the physiological BOLD noise model (2). For such a case and for a single voxel or ROI length equal to one we can describe as temporal signal-to-noise ratio (mean time course signal divided by standard deviation of time course) as:

$$TSNR_1=SNR/\{sqrt(1+(\lambda*SNR)^2)\}. [1]$$

Since the MRI signal is proportional to imaging voxel volume, as the ROI length increases the MRI signal increases as well. Therefore, we may now describe TSNR for ROI length equals to n as:

$$TSNR_n= n*SNR/\{sqrt(1+(n*\lambda*SNR)^2)\}. [2]$$

Since temporal signal-to-noise ratio is the inverse of Weisskoff relative signal deviation ($TSNR=1/F_1$), we expect that $1/TSNR_n$ should describe the plot Fn versus ROI length. Equation 2 also predicts that: a)for n=1 and low scanner-related noise $TSNR_1$=SNR; b) for n=1 and high scanner noise TSNR<SNR; c) n>>1 TSNR=1/λ, where λ characterized scanner performance and this constant should be a sensitive marker for a given hardware setting (due to hardware related imperfections).

Material and Methods: To test our model, experiments on silicon oil spherical phantom were conducted. Imaging was done on the 3T General Electric Excite3 MRI scanner (3T/90cm, a whole body gradient inset 40mT/m, slew rate 150 T/m/s, a whole body T/R RF coil) equipped with 16 channel high bandwidth receivers. Standard T/R birdcage head coil was used for signal reception. For fast imaging single shot full k-space gradient echo EPI with matrix size 64x64 and 128x128, TR=3s, TE=20,30,40,60,80 and 120 ms, flip angle 90°, bandwidth 250kHz, FOV=24, slice=4mm, gap=1mm, 16 axial slices.

Results: Figures 1 and 2 show $1/TSNR_n$ simulation results. The effect of SNR for given λ is shown on Figure 1. Changes in λ for two given SNR values are shown on Figure 2. Figure 3 shows experimental WP obtained with silicon oil phantom for different TE (symbols). Solid lines represent fit of $1/TSNR_n$ to the data. Figure 3 is the experimental verification of simulations from Figure 1. Figure 4 shows experimental WP obtained with silicon oil phantom for two different EPI in-plane resolutions and illustrate simulations from Figure 2.

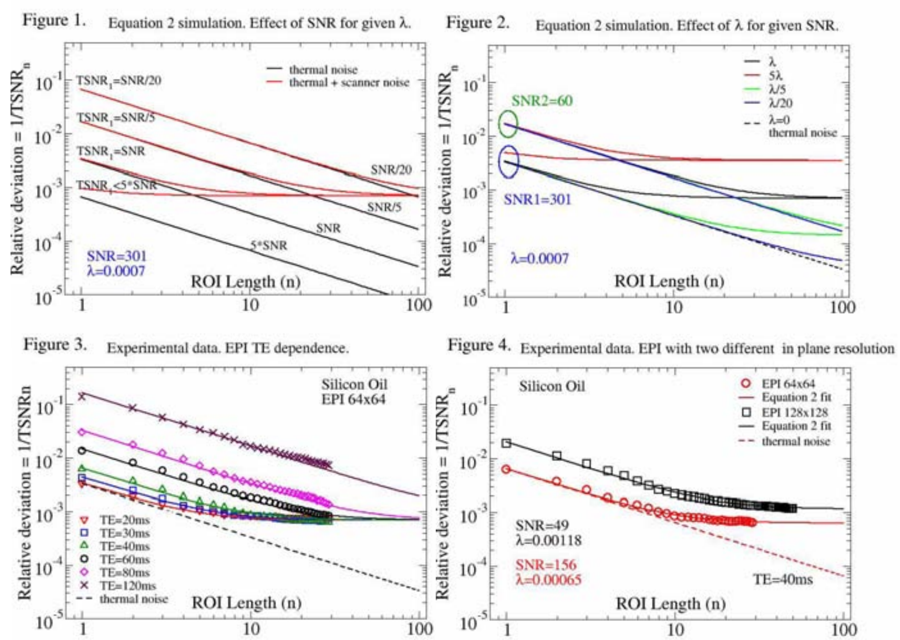

Figure 1. Equation 2 simulation. Effect of SNR for given λ.

Figure 2. Equation 2 simulation. Effect of λ for given SNR.

Figure 3. Experimental data. EPI TE dependence.

Figure 4. Experimental data. EPI with two different in plane resolution

Discussion: We have introduced an analytic model and formula to describe the Weisskoff EPI temporal stability test. In the formula derivation we have drawn an analogy with a “physiological noise” model in fMRI. We have assumed that system/scanner-related noise is proportional to the MR signal. Proportionality constant λ is thought to be specific for given scanner hardware settings/imperfections and reflects deviation from the thermal-only noise system. To describe WP fully, both SNR and λ are needed. The introduced formula results in the following interesting predictions. First, for the given λ deviation from thermal-only, the WP0 plot depends on available SNR. For the low SNR situation, deviations start at a much higher n than for high SNR systems (Figure 1 and 3). In a case such as this, WP plot looks better for low SNR systems and can mislead performance judgment. Second, for high SNR and large λ, single voxel TSNR can be smaller than SNR (Figure 1), just as in fMRI data, due to the dominant role of physiological noise (2). Third, it is possible to get two WP plots with similar deviations from thermal-only WP0 (Figure 2, black line with SNR=301 and λ/20, red line with SNR=60 and 5λ). In that case, both SNR and λ differ for each curve, but deviations from WP0 look similar. Finally, for different hardware settings, and due to hardware imperfections, it is expected that λ should differ (Figure 4).

Conclusion: We have proposed a simple model and have derived an analytical formula to describe the Weisskoff EPI temporal stability test. We have also shown an analogy with physiological noise models in oxygenation-sensitive fMRI. Simplicity of this analytical approach can be used to characterize and quantify MRI scanner performance for a given hardware setting and gain insight in scanner-related noise contributions to human fMRI data.

References: 1) Weisskoff R. MRM 36:643 (1996); 2) Krueger et al. MRM 46:631 (2001)