Modelling temporal stability of EPI time series acquired with multi-channel receiver coils: treatment of noise correlation

C. Hutton[1], A. Lutti[1], and N. Weiskopf[1]
[1]Wellcome Trust Centre for Neuroimaging, UCL Institute of Neurology, University College London, London, United Kingdom

Introduction

For fMRI studies, a model has been proposed to characterize temporal signal-to-noise ratio (tSNR) as a function of image SNR (SNR_0) in EPI time series allowing physiological noise to be separated from thermal noise [1]. The form of the model in [1,2] is only valid for fMRI data acquired with a single channel receiver coil. We extend the model to allow for state-of-the-art multi-channel acquisition mode, commonly used to increase sensitivity. We show that by including an additional scaling factor we can account for noise correlation between different receiver channels [3]. Furthermore, in the special but commonly used case of square-root-of-sum-of-squares reconstruction (SRSS), the estimated scaling factor provides a measure of noise correlation. We establish face validity of the extended model using Monte Carlo simulations and demonstrate improved model fit for task-free fMRI data acquired at 7T.

Theory

Following [1,2] the total noise in an image time course acquired using a single channel receiver coil (σ_1) is related to thermal (σ_0) and physiological (σ_p) components by $\sigma_1^2 = \sigma_0^2 + \sigma_p^2$. If the true image SNR is defined as $SNR_0 = S/\sigma_0$ and $\sigma_p = \lambda S$, where S is mean signal intensity and $1/\lambda$ corresponds to signal dependent degradation of tSNR, then from [1], for the 1-channel case the relationship between $tSNR_1$ and SNR_0 is given by $\mathbf{tSNR_1 = SNR_0/(1+\lambda^2 SNR_0^2)^{1/2}}$ **(Eq 1)**.

For a receiver coil with $n \geq 1$ channels, we assume that noise correlation scales the thermal noise component by a factor K_n so (in the absence of physiological noise) noise $\sigma_n := K_n\sigma_0$. We can then extend Eq 1 to $\mathbf{tSNR_n = SNR_0/(K_n^2+\lambda^2 SNR_0^2)^{1/2}}$ **(Eq 2)**.

By measuring $tSNR_n$ for different values of true image SNR_0 (e.g. by changing flip angle, voxel size or echo time), K_n and λ_n can be estimated from Eq 2. From [3], in the special case of a two channel coil, the maximum deviation of noise for the correlated compared to the uncorrelated case is given by $\mathbf{\sigma_2^2 \leq \sigma_0^2 (1 \pm \rho_{12})}$ where ρ_{12} is the correlation coefficient between the two coils. From this we note that K_n^2 provides the upper limit for the effect of noise correlation on the measured variance, i.e. $\mathbf{K_2^2 = (1+\rho_{12})}$ for maximal positive correlations and identical signal levels from both channels.

Methods

Monte Carlo simulation: SRSS reconstructed image time series were generated from simulated complex data with 10 different mean signal levels (S), thermal noise level (σ_0) = 1, and physiological noise with signal dependence $1/\lambda=100$. For each time point an image containing noise only was also generated. The simulation was performed for a 2-channel coil with $\rho_{12}=0.33$ (30% noise correlation).

Human data: A 7T whole body MR-system (Siemens Healthcare, Erlangen, Germany) using 24-channel receive head coil with dedicated CP coil for RF transmission (Nova Medical, Inc., Wilmington, MA) was used to acquire 5 EPI time series in 5 subjects with flip angles = 8, 16, 26, 38 and 70º. 20 EPI volumes were acquired with no RF excitation to provide noise only images. EPI acquisition parameters: matrix=64x64, resolution=3x3x2mm^3, slices=40, TE=25ms, volume TR=2s, BW=2300 Hz/Px, echo spacing=0.5ms.

Data analysis: We calculated $tSNR_n$=(mean(S)/standard deviation(S)) and SNR_0=mean(S)/(σ_0) where σ_0 = standard deviation in noise images as defined in [3] which is unaffected by noise correlations. The models defined by Eq 1 and Eq 2 were fitted to $tSNR_n$ and SNR_0 measurements to estimate λ (using Eq 1) and K_n and λ (using Eq 3) and sum-of-squares errors (SSE) for the fits were compared.

Results

For both simulated data (fig. 1) and human data (fig. 2), Eq 2 (red line) gives an improved fit to the data compared to Eq 1 (blue line) as also reflected by the SSEs in table 1. For simulated data, Eq 2 has correctly estimated $1/\lambda=100$ and $K_n^2=(1\pm\rho_{12})=1.33$.

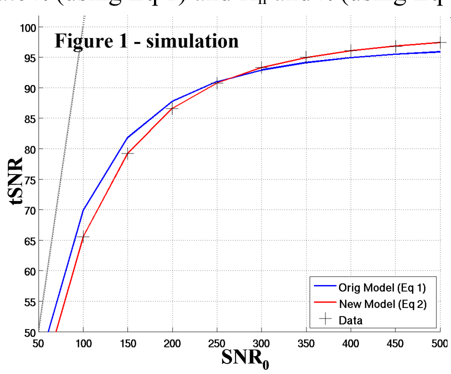

Figure 1 - simulation

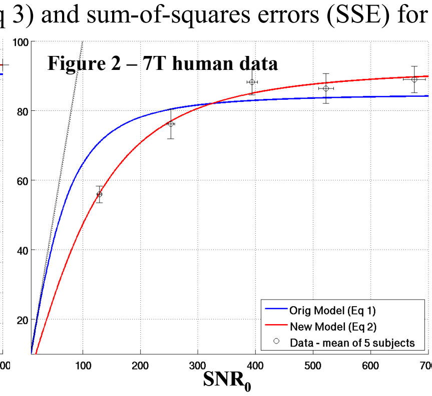

Figure 2 – 7T human data

Table 1	Sim. data	7T data
# receivers	2	24
Eq 1 – original model		
$1/\lambda$	98.0	84.7
SSE	57	298
Eq 2 – extended model		
$1/\lambda$	100	92.6
K_n^2	1.33	3.32
SSE	0.03	14

Discussion

We have shown that our extension to the model proposed in [1] gives an improved fit to data where noise correlations are present. In the case of a 2-channel coil, our simulation demonstrates that K_n is directly related to the noise correlation. Although methods have been proposed to correct for noise correlations at the reconstruction stage [4], users commonly use SRSS reconstruction for simplicity and robustness. The proposed extended model allows for the characterization of tSNR and physiological noise with data acquired using multi-channel receiver coils.

References 1) Kruger and Glover, 2001, MRM; 2) Triantafyllou et al., 2005, Neuroimage; 3) Constantinides et al., 1997, MRM; 4) Kellman and McVeigh, 2005, MRM

Acknowledgements: Funded by the Wellcome Trust[1],