Physiological Noise in Gradient Echo and Spin Echo EPI using Multi-Channel Array Coils

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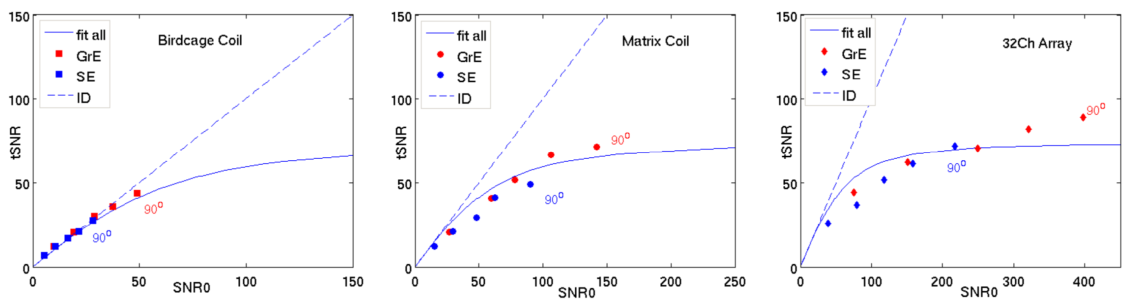
Introduction: SNR in the fMRI time series (tSNR) is dominated by physiological modulations of the signal (physiological noise) especially at high field strengths. Previous studies have shown that the relationship between tSNR and thermal image SNR (SNR_0) is well described by a model where physiological noise (σ_p) is viewed as a modulation of the signal (S); i.e. $\sigma_p = \lambda S$, where λ is a constant. (1, 2) However these studies have focused on the more commonly used gradient echo (GRE) EPI acquisitions. Possible benefits from spin echo (SE) fMRI at high field has motivated an analysis of the physiological noise properties of SE EPI time series compared to GRE. (3) This study suggested a qualitatively different behavior for SE physiological noise, for example, concluding that SE physiological noise does not scale with signal intensity.(3) Comparison with the GRE studies is, however, confounded by their differing analysis and acquisition methods.

We evaluate the tSNR in both GRE and SE single-shot EPI time series data and compare tSNR to SNR_0 using the model introduced by Krueger.(2) We modulate the SNR_0 by using different excitation flip angles as well as single channel and multiple channel array coils differing in sensitivity by nearly a factor of 8. The use of array data requires a more complex analysis to generate SNR_0 (4), but it is important to validate the noise model with array acquisitions since most fMRI experiments now use array coils. Our findings suggest that the relationship between tSNR and SNR_0 can be well parameterized by the Krueger model for both SE and GRE time-series and for array data, with only a 20% difference in λ for GRE and SE acquisitions. This suggests that when SNR_0 is modulated in this way, the single-shot SE physiological noise can be modeled as proportional to the signal.

Methods: Data from three normal subjects were acquired using a 3T Siemens MAGNETOM Trio, a TIM System (Siemens Medical Solutions, Erlangen Germany). Three different head coils were used in each subject; a transmit/receive birdcage volume coil, a receive-only 12Channel Matrix coil and a 32Channel phased array helmet coil. (5) Fully relaxed resting state EPI images were collected using a single-shot gradient echo (GRE) and a single-shot spin echo (SE). Data were collected at five different flip angles (12°, 24°, 37°, 53°, 90°) using TR=5400ms, ten 4mm thick slices, 60 time points, FOV=240x240mm^2, matrix=128x128, TE=30ms and 75ms for GRE and SE respectively. Data at flip angle 0° were also obtained to determine the thermal image noise. Analysis was performed in areas of cortical gray matter by user-defined regions of interest. The EPI images were reconstructed offline with custom software for ghost correction, and regridding in the readout direction to compensate for ramp sampling. No anti-aliasing or k-space filters were applied to the data. Array data was combined with the root Sum-of-Squares method.

SNR_0 was estimated using the method of Kellman et al. for a root Sum-of-Squares combination to account for the influence of the effective noise bandwidth on the noise estimates and the effect on the noise distribution due to the combination of magnitude images collected from multiple channel coils. (4) Time-series SNR (tSNR) was determined as the mean pixel intensity across the time points divided by the temporal standard deviation of the same ROI. The relationship between tSNR and SNR_0 was fit to the model of Krueger et.al., (2) which assumes $\sigma_p = \lambda S$ to obtain Eq. 1. The data was then fit to obtain a value for the parameter λ.

Results: Figures 1 and 2 illustrate the dependence of tSNR on SNR_0 when SNR_0 is modulated by flip angle and choice of receive coil. Blue and red points indicate the SE and GRE acquisitions respectively. Squares, circles and diamonds correspond to Birdcage coil, Matrix coil and 32Channel array. Fitting all the data to the Krueger model gave a λ=0.0136 giving an asymptote $tSNR_\infty$ = 73.5. For the GRE-only data, λ=0.0125 giving $tSNR_\infty$ = 79.7, while for the SE λ=0.0162 giving $tSNR_\infty$ of 61.76.



$$tSNR = \frac{SNR_0}{\sqrt{1+\lambda^2 SNR_0^2}} \quad \text{(Eq. 1)}$$

Fig. 1 tSNR as a function SNR_0 at different flip angles for SE (blue) and GRE (red) for the Birdcage coil (left), 12Channel Matrix coil (middle) and 32Channel coil (right). The data is shown with the identity line and the fit to Eq. 1 using all of the data.

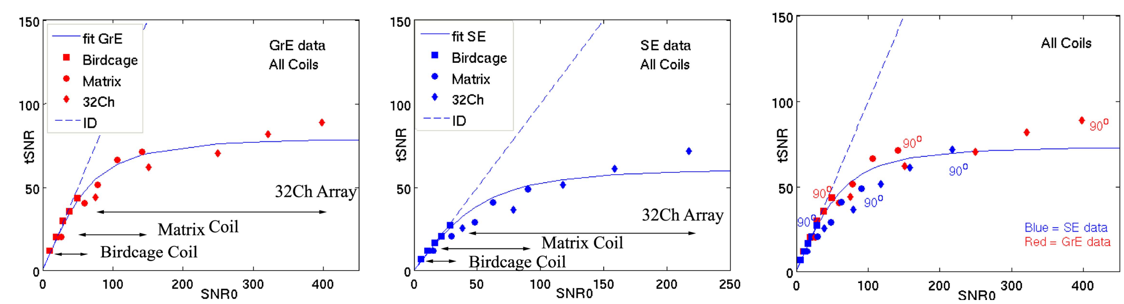


Fig. 2 tSNR vs SNR_0 for all coils. GRE alone (left) and SE alone (middle) as well as all data plotted on the same graph (right). Also shown is the fit to Eq. 1 using only the data shown in the respective plot.

Discussion: We demonstrate the asymptotic relationship between tSNR and SNR_0 for single-shot SE EPI and GRE EPI acquisitions. Additionally we extended previous studies to the use of multiple receive coils. Although the SE data was observed to have lower thermal and asymptotic time-series SNR and thus a different proportionality constant between signal strength and physiological noise, a different noise model was not required. It is likely that differences between these conclusions and that of the Yacoub study (3) result from the very different analysis and acquisition methods used. For example Yacoub et al. used multi-shot EPI rather than single shot. Also, the method used to vary the image SNR_0 differed. We use flip angle and coil choice to modulate SNR_0 while Yacoub et al. used spatial smoothing of the acquired images. It has been pointed out that spatial smoothing has unique properties since the images have the same resolution at acquisition (when physiological processes are present) and are transformed to the lower spatial resolution in a manner that does not involve physiological processes; smoothing. (6) Additionally Lowe et al. (7) has pointed out that physiological noise, unlike thermal noise, might be unevenly distributed in k-space and therefore differently effected by smoothing. The array data provided a reasonable fit to the model, but some deviation for the 32Channel data suggested that the noise model may need to be re-evaluated to take into account the non-linearity and lack of rigorous handling of noise covariance across channels in the root Sum-of-Squares array combinations.

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