Physiological Noise in Gradient Echo and Spin Echo EPI at 3T and 7T

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Introduction: Sensitivity of functional MRI at high field strengths (e.g. 3T and 7T) is restricted by signal fluctuations due to physiological processes in the brain. Because physiological modulations scale with the amplitude of signal intensity in the fMRI time-series, previous studies [1,2] investigated the physiological noise (σ_p) dependence on acquisition parameters and field strengths, demonstrating that increases in image SNR obtained from 7T acquisition produced only modest increases in time-course SNR, especially at lower spatial resolutions. Although physiological noise has been thoroughly evaluated in Gradient Echo (GrE) EPI acquisitions, Spin Echo (SE) EPI has been less studied[3]. It has been suggested that SE EPI is a better choice for high field fMRI studies, due to its increased sensitivity to the microvasculature. In addition, Yacoub et. al suggest that SE physiological noise might have different properties than GrE, for example suggesting the physiological noise at 7T is independent of signal strength and spatial resolution. In this study we investigate the physiological noise in both SE and GrE EPI sequences as a function of (thermal) image SNR (SNR_0) by modulating the spatial resolution, receive coil, and field strength. Our findings demonstrate that physiological noise in both sequences behave similarly and the relationship between time-course SNR (tSNR) and SNR_0 is well described by the Krueger et al model[2].

Methods: Four subjects were studied using a 3T TIM Trio system with product head coils (birdcage and 12ch) and a custom built 32ch array. Two subjects were scanned on a 7T system, (Siemens Medical Solutions, Erlangen Germany) using a home-built 32ch array of similar layout to the 3T array. Fully-relaxed resting-state EPI images were collected using two different sequences; single-shot GrE and SE EPI. The fMRI time-series were collected at six in-plane resolutions (1x1mm^2, 1.5x1.5mm^2, 2x2mm^2, 3x3mm^2, 4x4mm^2 and 5x5mm^2) using TR=5400ms, 60 measurements, and ten 3mm thick slices. The TE was set to values commonly used to maximize BOLD; 30ms and 20ms for GrE at 3T and 7T and 75ms and 55ms for SE. The thermal image noise (σ_0) was obtained from images without RF excitation (flip angle 0°). All EPI images were reconstructed offline with custom software for phase correction, regridding along the readout direction and apodization filtering. SNR_0 was calculated using the method of Kellman et.al [4] in order to allow direct comparison between the array SNR_0 and tSNR. This accounts for the effective noise bandwidth and effects from the combination of multichannel magnitude images. Array data was combined with the root Sum-of-Squares method. Time-course SNR (tSNR) maps were generated from the mean pixel value across time points divided by their temporal standard deviation. Measurements of tSNR and SNR_0 were evaluated in cortical gray matter ROI and tSNR was plotted as a function of SNR_0 for the different in-plane resolutions, receive coils and field strengths and were parameterized using the model of Krueger et.al. [2] with the asymptotic tSNR ($1/\lambda$) obtained from a non-linear least squares fit.

Results: Figure 1 shows the 3T and 7T tSNR, SNR_0 relationship for GrE (red) and SE (blue) over the range of spatial resolutions and receive coils. The value of λ derived from the data in each graph is printed on the graph. The similarity between the λ values for GrE and SE as well as the close correspondence between the data and the Krueger model suggests that physiological noise behaves similarly across sequence type (GrE, SE), resolution and field strength. In all cases, the larger voxel volumes became increasingly physiological noise dominated. However, at 3T the higher resolution time series had sufficient thermal noise so that the tSNR was consistently improved by the use of the 32ch array coil; for the 1.5x1.5x3mm^3 acquisition the tSNR was increased by 57% (GrE) and 50% (SE) compared to 12ch coil.

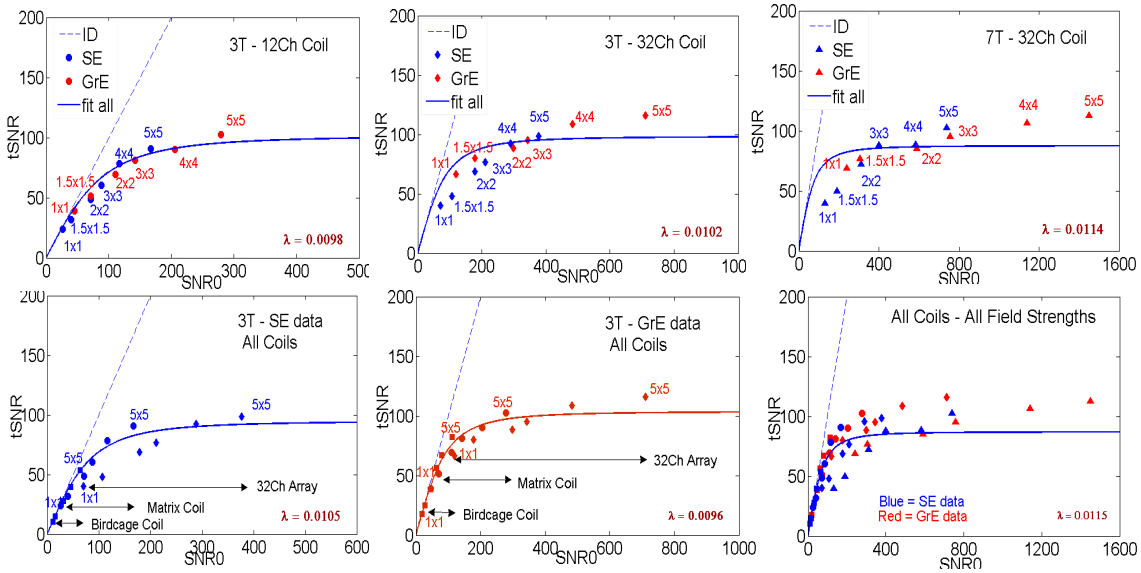

Fig. 1. tSNR as a function of SNR_0 at different in-plane resolutions at 3T and 7T, for SE (blue) and GrE (red) data sets and fit to the Krueger model. Squares, circles and diamonds represent the 3T data for Birdcage coil, 12ch and the 32ch array respectively. Triangles correspond to 7T 32ch data. The dotted line is the line of identity (tSNR=SNR_0).

Discussion: We demonstrate that the 3T and 7T fMRI time-course SNR is near its asymptotic limit when highly parallel arrays are used for both GrE and SE. However, when higher spatial resolutions were examined, the limitations in tSNR from physiological noise were significantly mitigated. We extended our previous work to include SE EPI fMRI time-series and showed that although SE data have lower image SNR it was not required to use a different model. At each field, tSNR increased monotonically with voxel volume, but the largest gains in tSNR as a function of voxel size occurred at the highest spatial resolution. At coarser spatial resolutions, both field strengths and sequences showed asymptotic behavior, with the higher field strengths nearing the asymptote at smaller voxel volumes. The different conclusions between this work and that of the Yacoub study [3] is possibly due to the differences in image acquisition and analysis. In this work, signal was modulated by receive coils, spatial resolutions and field strengths, while Yacoub et al. used spatial smoothing of the acquired images to generate data on various resolutions.

References: 1) Triantafyllou C, et al., Neuroimage, 26(1):243-50, 2005, 2) Krueger G, et al, MRM,46:631-7, 2001., 3) Yacoub E, et al. Neuroimage, Feb 1;24(3):738-50, 2005, 4) Kellman P, et al. MRM, 54(6):1439-1447, 2005.