Effect of Acquisition Parameters on Physiological Noise in fMRI at 1.5T, 3T and 7T

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Introduction

Spatial resolution and sensitivity in fMRI are typically limited by the loss of signal-to-noise ratio, due to instrumental sources of error, including thermal noise and electronic instability, and signal fluctuations associated with uncontrolled physiological processes. In addition to respiratory and cardiac cycle contributions, the physiological noise also consists of a noise element with BOLD-like TE dependence [1], and spatial correlation within gray matter [2], [3]. Previous studies have shown that noise fluctuations in an fMRI time-course are dominated by physiological modulations of the image intensity with secondary contributions from thermal image noise and that these two sources scale differently with signal intensity, susceptibility weighting (TE) and field strength. In this study we examine the effects of the magnetic field strength on the physiological noise at 1.5T, 3T and 7T. In addition, we extended previous observations to higher spatial resolutions, where thermal image noise dominates the time-course variance and thus alter the effective tradeoff between image SNR and time course SNR. In this high spatial resolution regime, increases in image SNR gained by use of the 7T system still translate to substantially improved time-course SNR.

Methods

Data from 5 healthy volunteers were acquired at three different field strengths, on a Siemens Sonata 1.5T, Allegra 3T and a Siemens 7T system (Siemens Medical Solutions, Erlangen Germany). Single shot fully relaxed GE EPI images were collected at six different in-plane resolutions ($1mm^2$, $1.5mm^2$, $2mm^2$, $3mm^2$, $4mm^2$, $5mm^2$) using TR=5400ms, ten 3mm thick slices with a 3mm slice gap, 60 time points, and a TE of 40ms, 30ms, 20ms for 1.5T, 3T and 7T respectively. In all cases, images at flip angle 0° were also obtained to determine the thermal image noise. For comparison, time series data using the same parameters were also acquired on a loading phantom. The image SNR (SNR_0) and the time-course fMRI SNR (tSNR) were measured in ROIs defined in cortical gray matter. SNR_0 for a given pixel was calculated as the mean pixel value for all the images in the time-series divided by the standard deviation of the thermal noise of the time-series acquired with no RF excitation (zero flip angle images). Temporal SNR (tSNR) in a given pixel was determined from the mean pixel value across the 60 time points divided by its temporal standard deviation. The tSNR was then plotted as a function of SNR_0. To study the "BOLD like" noise contribution, the image time course variance was examined by varying the TE of the EPI sequence at 3T and 7T. A multi-echo EPI sequence was used with TR=3000ms, ten 3mm thick slices with 3mm slice gap, 60 time points, and variable TE between 20-100 ms and 15-70 ms for the 3T and 7T respectively. The ratio of BOLD-like to thermal noise was plotted as a function of TE. Analysis was done using the model described in Krueger et al [2].

Results

Figure 1A illustrates the dependence of both the tSNR and SNR_0 on spatial resolution for 1.5T, 3T and 7T. Results demonstrate an increase in the relative contribution of physiological noise with field strength, which reaches an asymptotic with increasing SNR_0. At a given spatial resolution, the ratio of physiological to thermal noise always increased with field strength. However at higher spatial resolutions the limitations in tSNR from physiological noise were significantly mitigated. For example, at $3x3x3mm^3$, the ratio of physiological to thermal image noise was 0.61, 0.89, and 2.23 for 1.5T, 3T and 7T. At a resolution of $1x1x3mm^3$, however, this ratio was 0.34, 0.57, and 0.91 for 1.5T, 3T and 7T for TE near T2*. Figure 1B shows the physiological to thermal noise ratio as a function of voxel volume for each of the three field strengths. Figure 1C illustrates the ratio gain of tSNR obtained from going to higher field strength. Figure 1D shows the measured BOLD-like component of the physiological noise as a function of TE at 3 different resolutions for the 7T. The observed TE dependence was well described by the expected BOLD contrast function with maximum BOLD noise near T2*.

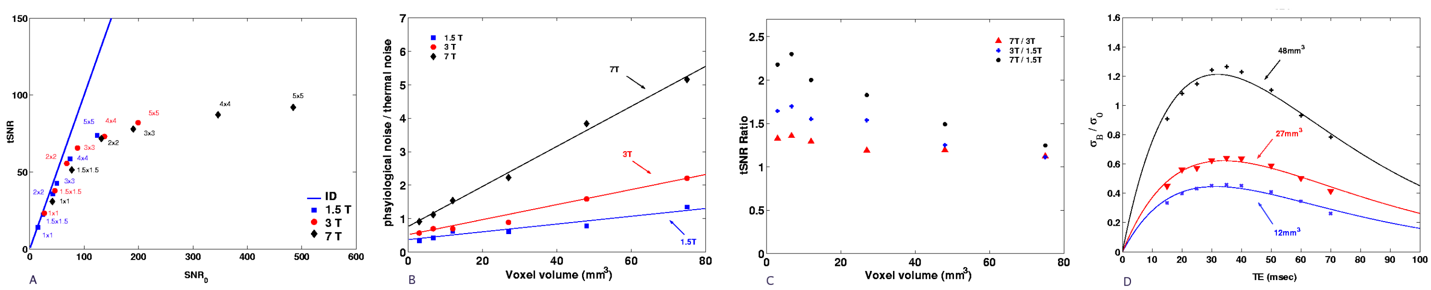

Figure 1. (A) tSNR as a function of SNR_0 at different spatial resolutions. Magnetic field strengths of 1.5T, 3T and 7T are represented respectively by squares, circles and diamonds. Labels show the in-plane resolution in mm^2 at 3mm slice thickness. Measurements derived from areas of cortical gray matter averaged over 5 subjects at each field strength. In **(B)** the ratio of physiological to thermal noise is given as a function of voxel volume. In **(C)** the ratio of the tSNR at different field strengths as a function of voxel volume is illustrated. The ratios of 7T to 3T, 3T to 1.5T and 7T to 1.5T are illustrated with triangles, crosses and stars respectively. **(D)** shows the ratio of BOLD-like physiological noise to thermal noise (σ_B/σ_0) as a function of TE, for voxel size of $12mm^3$, $27mm^3$ and $48mm^3$ at 7T. Solid lines represent the fit to the noise model [2].

Conclusion

This work verifies that the temporal SNR of the fMRI experiment reaches a plateau at high image SNR. For our studies, once the SNR_0 reached an SNR of ~100, further improvements in SNR_0 are expected to yield only marginal increases in the tSNR. At high image resolutions, however, the SNR_0 is reduced to a point where the tSNR was not dominated by physiological noise. The higher resolution experiments were shown to have the potential to benefit significantly from the use of field strengths of 7T and above. Although the physiological noise dominated tSNR at larger voxel volumes and higher field strengths, it was possible to obtain thermal noise dominated images (σ_p/σ_0 <1) at all field strengths. When the spatial resolution was high enough to assure that the time course was dominated by thermal image noise, improvements in SNR from improved RF coil design or even higher field strengths are likely to translate into improved time-course SNR.

References 1) Krueger G, et al, MRM,45:595-604,2001, 2) Krueger G, et al, MRM,46:631-637,2001, 3) Weisskoff R, et al, ISMRM,p7,1993.
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