Physiological Noise in fMRI: Comparison at 1.5T, 3T and 7T and Dependence on Image Resolution

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Introduction

One of the primary motivations for the development of high-field MR imaging has been to extend the boundaries of spatial resolution and sensitivity. Sensitivity is generally limited by two sources of variance: instrumental sources of error including thermal noise and electronic instability, and signal fluctuations associated with uncontrolled physiological processes. Since physiological fluctuations represent a multiplicative modulation of the image signal, decreases in instrumental measurement error will not eliminate them. Previous studies [1,2] have demonstrated an asymptotic relationship between the variance in the SNR time-course and the component of variance associated specifically with thermal image noise at a fixed moderate spatial resolution. In this study we extended these observations to higher spatial resolutions, where thermal image noise dominates the time-course variance to assess the benefit of the increased image SNR afforded by higher field systems. Our findings demonstrate that trading the increased image sensitivity for improved resolution allows the user to lower the physiological to thermal noise ratio and operate in a regime where increases in image sensitivity still translate to improved fMRI time-course variance.

Methods

Two comparative studies were performed with a volume head coil at three different field strengths on a Siemens Sonata 1.5T, Allegra 3T and a Siemens 7T system (Siemens Medical Solutions, Erlangen Germany). In the first study, single shot fully relaxed gradient echo EPI images were collected at five different flip angles (12°, 24°, 37°, 53°, 90°) using TR=5400ms, 3 slices, slice thickness=4mm, 60 time points, FOV=240x240mm^2, matrix=128x128, and a TE of 20ms, 30ms, 40ms for 7T, 3T and 1.5T respectively. The same sequence parameters were used in the second study except that the flip angle was held constant at 90° and resolutions of 1x1x3mm^3, 1.5x1.5x3mm^3, and 1.9x1.9x4mm^3 were used. In all cases, images at flip angle 0° were also obtained to determine the thermal image noise. To avoid partial volume effects, gray matter areas were segmented. Two quantities were then estimated, the image SNR and the image-to-image variance. SNR in the time series was determined as the mean pixel value across time points divided by the temporal standard deviation of the same pixel. The time-course SNR was then averaged over the gray matter ROI. The fMRI time-course SNR was plotted as a function of image SNR (SNR_0). Temporal physiological variance maps were produced, to illustrate the spatial distribution of the physiological noise across the brain.

Results

Figure 1a illustrates the dependence of both the image and temporal SNR on signal strength as modulated by five different flip angles for 1.5T, 3T and 7T. The results agree with those demonstrated for 1.5T and 3T [1]; i.e., higher flip angle excitation produces higher physiological noise within each field strength, and the characteristic was observed at a field strength of 7T. Results in figure 1b, using voxel volumes of 3mm^3, 6.75mm^3, and 14.44mm^3, demonstrate an increase in the relative contribution of physiological noise with field strength. However, image thermal noise increased with the higher resolution data reducing the percentage contribution of physiological noise. While the time-course SNR at a given resolution always improved with field strength, the higher resolution data produced larger improvements. For example the 7T time course SNR was 3.3 fold larger than that seen at 1.5T for 6.75mm^3 resolution and 3.9 fold higher for the 3mm^3 resolution data set. To achieve the time course SNR observed at 3 mm^3 at 7T, it would be necessary to use a voxel volume of 14.44 mm^3 at 1.5T. These results indicate that time course SNR is physiologically limited. Increasing the field strength lowers the voxel size where at which this limit is approached.

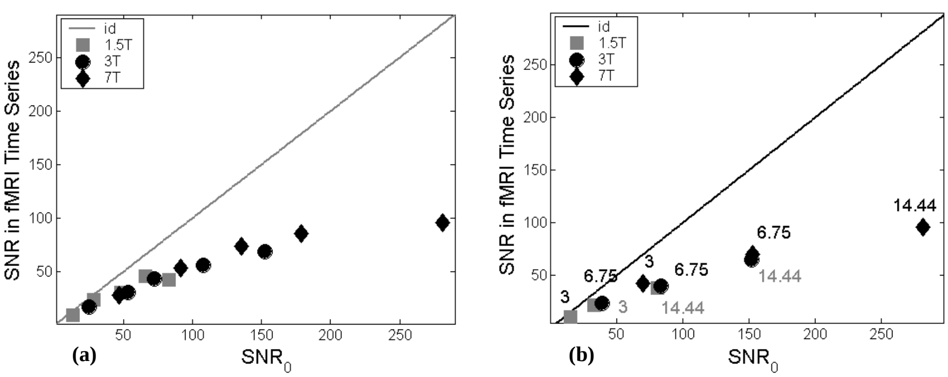

Figure 1. SNR in the fMRI time series as a function of image SNR. Magnetic field strengths of 1.5T, 3T and 7T are represented respectively by squares, circles and diamonds. In **(a)** SNR modulations are observed with variable flip angles. In **(b)** the variations of image SNR is modulated by altering the image resolution. Voxel volume is given in mm^3, where 3, 6.75 and 14.44 mm^3 equate to voxel dimensions of 1x1x3, 1.5x1.5x3 and 1.9x1.9x4 mm^3 respectively.

Conclusion

The physiological component of time series noise is proportional to image signal intensity and accounts for an increasing proportion of the total time series variance at higher field strengths. However at the high spatial resolutions desirable for many experiments envisioned with high field systems, thermal noise is sufficiently high that there is nonetheless substantial benefit from the increased signal strength at these higher fields. This effect suggests that increased image SNR from higher field strength and other sources such as improved RF coils should be traded off for higher spatial resolutions. We are also investigating field strength dependence of BOLD contrast at 1.5, 3, and 7T, which is the other critical component of the contrast-to-noise ratio that ultimately determines sensitivity in functional experiments. In addition to using image resolution to reduce the effect of physiological noise, recording physiological parameters and using these to model variance can also reduce the impact of physiological noise.

References: 1) Krueger G, et al, MRM,45:595-604,2001, 2) Krueger G, et al, MRM,46:631-637,2001.

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