Effect of Smoothing on High Resolution fMRI Experiments at Higher Field Strengths

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Introduction: Sensitivity and specificity of BOLD fMRI maps are expected to improve with increasing field strength due to favorable increases in BOLD contrast, BOLD localization, and improved image sensitivity. The increase in image sensitivity with higher field, however, is not fully utilized at conventional spatial resolutions since the fMRI time-course noise is dominated by physiological noise. Thus, as higher image sensitivity is achieved through the use of better RF coils or bigger magnets, the physiologic noise increases proportionally. The result is that for high field fMRI at conventional image resolutions (27mm^3), increases in image SNR (SNR$_0$) result in only marginal increases in the SNR of the fMRI time-course (tSNR) [1]. Our previous work showed that by acquiring the functional images at higher spatial resolutions, it is possible to operate in a regime where thermal image noise dominates physiological noise[2]. In this regime, increased image SNR (e.g. from 7T acquisition), still translate into improved time-course SNR. While high spatial resolution functional maps are intrinsically desirable for some studies, it is not clear that voxel dimensions smaller than the cortical ribbon thickness are beneficial for applications where large areas of cortex are activated. While these studies are expected to benefit from the contrast and localization improvements at high field, analysis of the time-course SNR shows that they receive only marginal benefit from the increases in sensitivity. In this study, we examine the effect of spatially smoothing 7T high resolution EPI images down to conventional resolutions. The goal is to obtain the best of both worlds; thermal noise dominated images at acquisition which benefit from the sensitivity of high field, and increased tSNR from spatial smoothing images with largely spatially uncorrelated time-course noise. Our findings demonstrate that in contrast to conventional penalties associated with smoothing Fourier data, the resulting time-course SNR can be improved compared to direct acquisition at the desired resolution.

Methods: Data from 2 healthy volunteers were acquired using a TEM volume head coil on a Siemens 7T system (Siemens Medical Solutions, Erlangen, Germany). Single shot fully relaxed GE EPI images were collected at five different in-plane resolutions (1.5mm^2, 2mm^2, 3mm^2, 4mm^2, 5mm^2). The imaging parameters were TR=5400ms, ten 3mm thick slices with a 3mm slice gap, 60 time points, and a TE of 20ms. In all cases, images with no RF excitation were also obtained to determine the thermal image noise. Post processing analysis was employed to generate additional low resolution images by convolving the 1.5mm^2 high resolution scan with a Gaussian smoothing function. The FWHM was modulated to match the voxel size of the low resolution acquired images (FWHM=2mm^2, 3mm^2, 4mm^2, 5mm^2). The image SNR (SNR$_0$) and the time-course fMRI SNR (tSNR) were then measured in ROIs defined in cortical gray matter on both the original scans and the smoothed images. 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 zero flip angle. SNR$_0$ was corrected for Rayleigh distribution. 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$_0$. The ratio of the physiological to thermal noise was calculated form the measurements of tSNR and SNR$_0$: $\sigma_p / \sigma_0 = \sqrt{(SNR_0 / tSNR)^2 - 1}$ [2].

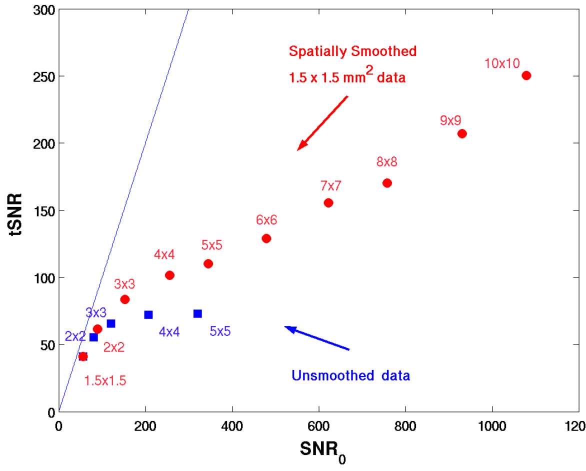

Figure 1. Time-course fMRI SNR (tSNR) as a function of image SNR$_0$ at different spatial resolutions. Blue squares represent the unsmoothed data, the stated resolution indicates the resolution of acquisition. Red circles indicate different degrees of spatial smoothing of the 1.5x1.5mm^2 data. Labels show the in-plane resolution in mm^2 at 3mm slice thickness. Measurements derived from areas of cortical gray matter at each resolution. The solid line corresponds to the line of identity (tSNR=SNR$_0$)

Resolution (mm^2)	Acquired Images σ_p/σ_0	Smoothed Images σ_p/σ_0
1.5x1.5	0.91	0.91
2x2	1.05	1.05
3x3	1.07	1.06
4x4	2.69	2.31
5x5	4.28	2.97

Table 1. Ratio of the physiological to thermal noise at 5 resolutions calculated from the acquired low resolution scans and the estimated smoothed images

Results: Figure 1 illustrates the dependence of both the tSNR and SNR$_0$ on spatial resolution. Squares indicate data analyzed at the resolution it was acquired. As shown in previous study [2], the tSNR has reached an asymptote; increasing SNR$_0$ from larger voxels result in only marginal increases in tSNR. The red circles indicate measured SNRs obtained from spatially smoothing the 1.5x1.5mm^2 data. For the smoothed data, tSNR increased monotonically with voxel size and is always higher than the corresponding voxel size obtained. Table 1 shows the calculated physiological noise to thermal noise ratio (σ_p/σ_0) for the acquired low resolution images and the generated smoothed. This ratio increased with spatial resolution in both cases however on the smoothed data (e.g. 5x5mm^2) there is a smaller fraction of physiological noise.

Conclusion: This study suggests that if a spatial resolution is desired where physiologic noise dominates the timecourse SNR, it may be advantageous to acquire at a high enough resolution where thermal noise dominates and then smooth to the desired resolution. For example, if 5x5mm2 maps are desired, smoothing EPI images acquired at 1.5mm resolution to 5mm resolution resulted in a 1.6 fold tSNR gain over the tSNR obtained from acquiring 5mm resolution data directly.

References 1) Krueger G, et al, MRM,45:595-604,2001, 2) Triantafyllou, et al, ISMRM, p 1071,2001.

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