Effects of Sensitivity Encoding and Physiological Noise on Temporal Signal Stability and fMRI at 7T

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INTRODUCTION

High field MRI scanners show increased signal-to-noise ratio (SNR) of MR images and increased contrast from blood oxygen level dependent (BOLD) effects in functional MRI (fMRI) relative to lower field scanners. However, increasing B_0 also increases magnetic field inhomogeneities, signal dropout, image distortion, and physiological noise effects in single-shot echo-planar fMRI [1]. Parallel imaging techniques such as Sensitivity Encoding (SENSE) can reduce these effects by traversing k-space more quickly, but also incur SNR penalties depending on the acceleration factor R, local geometry factor *g*, and other factors [2][3][4]. Here we examine the effects of changing R on a) the relative contributions of physiological noise to the total noise of an fMRI time series, b) fMRI sensitivity in terms of maximum t-value and total activated voxels, and c) the temporal signal-to-noise ratio (TSNR) of the time series at 7T.

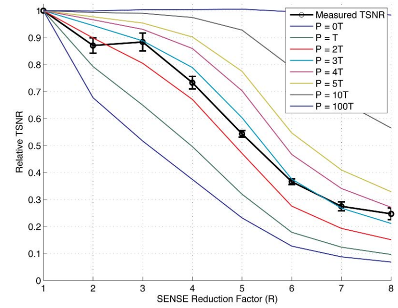


Fig. 1: Mean measured TSNR (black line) with theoretical TSNR curves as a function of R for varying contributions of physiological noise. Error bars represent the STDEV of TSNR across slices.

METHODS

Ten healthy volunteers were scanned on a Philips Achieva 7T scanner with a 16 channel SENSE receive-only head coil with an outer quadrature transmit coil. Subjects were presented with a flashing checkerboard (8Hz) [on 24s, off 24s] in four blocks. Each run was 192 seconds. Acquisition parameters: single-shot echo planar imaging at $1x1x2mm^3$; TR = 2s; TE = 25ms; FOV = $192mm^2$; Slices = 9; Images per run = 96; Partial Fourier factor H = 0.6; R = 1 through 8. fMRI data were slice-timing corrected, motion corrected, and realigned to the first volume in SPM5 (Wellcome Dept. of Cognitive Neurology, London, UK). Relative contributions of physiological noise to the total noise of each time series, maximum t-values, number of activated voxels, and whole-brain TSNR were measured. We evaluate relative TSNR in terms of *g, R,* total signal ($\overline{S_{full}}$), physiological noise (σ_P), thermal noise (σ_T), scanner noise (σ_S), and partial Fourier factor (H), and compare with a theoretical model as given in Eq 1.

$$TSNR_{SENSE} = \frac{\overline{S}_{full} \cdot \sqrt{H}}{\sqrt{(g \cdot \sqrt{R} \cdot \sigma_{T,full})^2 + \sigma_P^2 + \sigma_S^2}} \qquad (1)$$

RESULTS

Figure 1 shows the mean measured TSNR across slices and subjects as a function of R (black line) together with the family of theoretical curves based on Eq 1. These represent relative TSNR behavior with varying contributions of physiological noise relative to thermal noise. The correlation between our model and the measured TSNR is high for theoretical values of physiological noise equaling 2-4 times thermal noise (lines P = 2T through P = 4T). Figure 2 shows respiratory power in the frequency range 0.15 – 0.25Hz. As R increases, the relative power of the respiratory frequency decreases. At R = 1, the peak respiratory frequency accounts for 9% of the total power. At R = 2, it is reduced to 5.5%, then < 2% for R ≥ 4. Figure 3 shows activation maps corresponding to each R. Table 1 shows *g*-factors, maximum t-values, and total active voxels for each R. t-values and total activated voxels fall significantly beyond R = 5, while *g*-factors grow significantly beyond that point.

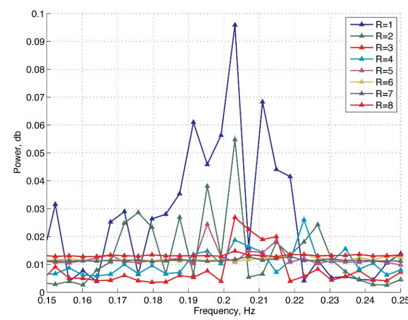
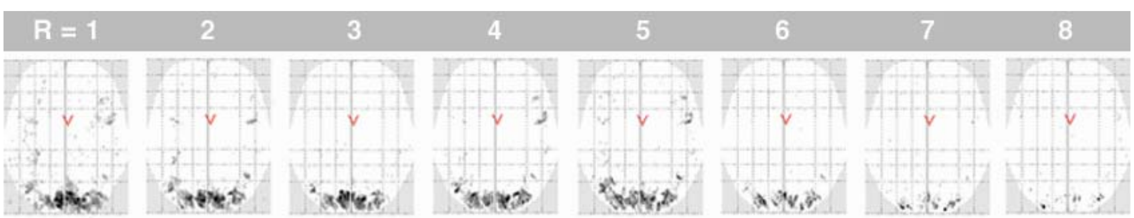


Fig. 2: Respiratory power decreases as R increases for one representative subject. At R ≥ 5, the ability to resolve the respiratory frequency is lost.

Table 1: *g*-factors, maximum t-values, and total activated voxels averaged across all subjects.

SENSE R	1	2	3	4	5	6	7	8
Mean *g*-factor	1	1.04	1.12	1.34	1.94	3.21	4.37	5.15
Max t-value	10.58	10.62	10.39	9.67	8.73	7.46	7.07	6.40
Active Voxels	2095	2846	1927	1658	1311	587	357	246

Fig. 3: Axial activation maps from a representative subject by R value. Activation drops significantly after R = 5.



DISCUSSION

We have examined the effects of changing SENSE acceleration factor *R* on the relative contributions of physiological noise to an fMRI time series, fMRI sensitivity, and TSNR. A simple model for TSNR behavior (Eq. 1) is in excellent agreement with the measured TSNR data. Our results show that the relative contributions of respiratory noise decrease significantly as R increases. This suggests that it may be possible to reduce or eliminate the contributions of physiological noise to fMRI data by acquiring a time series with a sufficiently high reduction factor. Around R = 5, the local geometry factor *g* surpasses its critical value and begins to grow, severely limiting the SNR and TSNR of the image data. This transitional point is where further improvements to coil design or field strength would begin to produce significantly increased SNR, TSNR, and fMRI sensitivity [5]. Acquiring data with a SENSE acceleration of R = 4 is an appropriate choice for single-shot EPI fMRI studies similar to ours at 7T. Parallel imaging coils with more elements may yield immediate and significant benefits for high field EPI fMRI.

REFERENCES

1) Raj et al. Phys. Med. Biol. 46 (2001) 3331-3340. 2) Preibisch et al. NeuroImage. 19 (2003) 412-421. 3) Pruessmann et al. Mag. Res. Med. 42 (1999) 952-962. 4) Triantafyllou et al. NeuroImage. 26 (2005) 243-250. 5) Wiesinger et al. NMR BioMed. 19 (2006) 368-378.