Physiological Noise in GRAPPA fMRI Time-series

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Introduction: Highly parallel detection of functional imaging time-series provides the potential for higher image Signal-to-Noise ratio (SNR_0) as well as decreased susceptibility distortions in echo-planar imaging. Because physiological modulations scale with the amplitude of signal intensity, previous studies [1, 2] investigated the time-series SNR (tSNR) gains of non-accelerated acquisitions. When 12ch and 32ch arrays are used at 3T, the increased image SNR offered by arrays, produces the greatest benefit in the tSNR for medium to small voxel volumes, where the thermal noise still contributes significantly to the time-series variance. In these cases, eliminating the thermal noise (with improved array coils) improves the fMRI time-series SNR (tSNR). For parallel imaging with acceleration factor R, it has been postulated that noise of the accelerated image increased by a factor of $g\sqrt{R}$ for the SENSE method, (where g is the g-factor), alters only SNR_0 and is relatively unimportant when the time series is physiological-noise dominated.[3] Thus the penalty of the noise amplification and k-space sample reduction depends on the relative contribution of physiological and image noise. This study (at 1.5T using 3.4x3.4x4mm^3 voxels and a SENSE R=2) showed that the SENSE acceleration reduced cortical SNR_0 by 34% and tSNR by 25%. Although this validated the basic model of how the g-factor and acceleration alter the time-series stability, the study was limited in studying only a single modest acceleration (R=2) on a single spatial resolution, where thermal noise is expected to dominate at 1.5T field strength. Finally, no study has been performed using GRAPPA [4], a commonly employed parallel reconstruction method with a spatially smoother noise enhancement, but with a less readily calculated noise enhancement. Here we examine the effect of GRAPPA acceleration, (R=1,2,3,4) on the tSNR at 3T with a 32 channel head coil for a number of image resolutions commonly used in fMRI.

Methods: Four healthy human subjects were imaged on a 3T Siemens TIM Trio System (Siemens, Erlangen, Germany) using a product 32ch phased array head coil (Siemens, Erlangen, Germany). Resting-state EPI measurements were acquired using a single-shot, gradient echo EPI sequence with TR=2000ms, TE=30ms and 150 time points. Data were collected at three resolutions (2x2x2 mm^3, 3x3x3 mm^3, 3x3x5mm^3) using parallel imaging reconstruction (GRAPPA) with acceleration factors of 1, 2, 3 and 4 at each resolution. Images with flip angle 0° were obtained to determine the thermal image noise for the non-accelerated acquisitions. For the purposes of the present study we assumed that the SENSE g-factor is the equivalent noise enhancement, 'g-factor' for GRAPPA. All EPI data were reconstructed offline with in-house software. To allow direct comparison between the array SNR_0 and tSNR, SNR_0 maps were generated using the method of Kellman et al. [5], which accounts for the effective noise bandwidth on the noise estimates and the effect on the noise distribution due to the combination of magnitude images collected from the 32ch array. These maps were then scaled by $g\sqrt{R}$ to include the noise enhancement of the accelerated images, which is not accounted for in the Kellman calculations. Time-series SNR (tSNR) maps were determined as the mean pixel intensity across the time points divided by the temporal standard deviation. Measurements of tSNR and SNR_0 were evaluated in a cortical gray matter ROI.

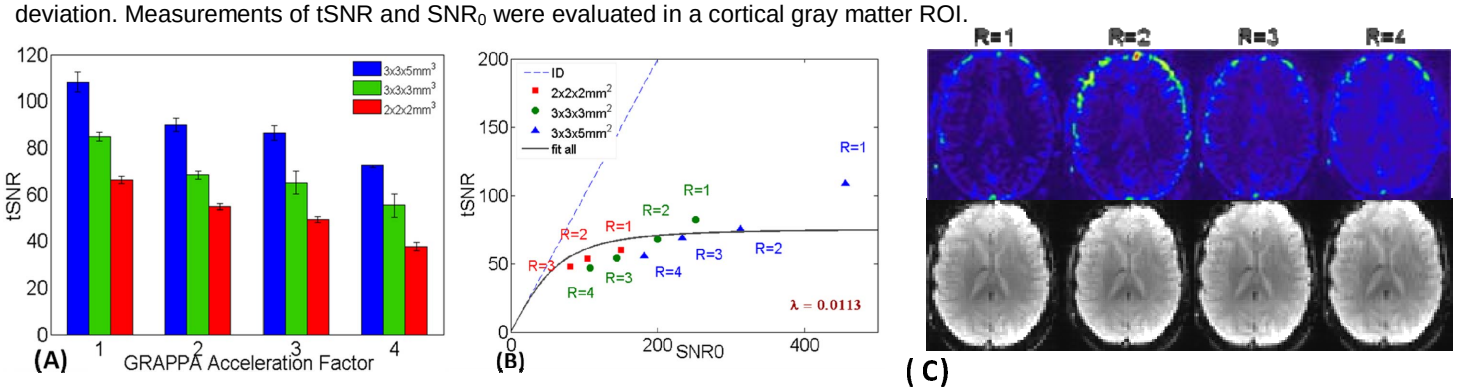

Figure 1 A) tSNR as a function of acceleration factor for each resolution. B) tSNR as a function of SNR_0 when SNR_0 is modulated by the resolution and acceleration factor. C) Recontructed images (bottom) and time-course variance maps for R=1,2,3,4 for the 3x3x5mm^3 acquisition.

Results and Discussion: Figure 1A shows the average tSNR over four subjects, as a function of resolution at acceleration rates R=1,2,3,4; tSNR decreases at higher resolutions as expected, but it is also reduced with R in all cases. For example, at the lowest resolution used (3x3x5mm^3), tSNR decreased by 34% between the R=1 and R=4 acquisition. For the higher resolution (2x2x2mm^3) the percentage decrease in tSNR between R=1 to R=4 is the greatest; 43%. Figure 1B shows the relationship of tSNR and SNR_0 as a function of resolution and R as well as the value for the tSNR asymptote (1/λ). The fit to Krueger model [6] suggests that the acceleration penalty ($g\sqrt{R}$) behaves like other modulators of SNR_0 such as field strength, voxel volume, flip angle and coil type. Figure 1C top illustrates the variance maps from subject 1, at resolution 3x3x5mm^3 for all 4 accelerations.

In this study, we extended our previous work [1] in characterizing the relationship between time-course SNR and image SNR to include accelerated fMRI time-courses by modulating spatial resolution and degree of acceleration.

References: 1)Triantafyllou C,et al. Neuroimage, 26(1):243-50,2005, 2)Ttriantafyllou C,et al. Proc. ISMRM, p2465, 2008. 3) de Zwart JA et al. MRM, 48(6):1011–1020, 2002, 4)Griswold MA, et al., MRM, 47(6):1202–1210,2002, 5)Kellman P, et al. MRM, 54(6):1439-1447,2005, 6) Krueger G,et al, MRM,46:631-637,2001.