Comparison of Thermal and Physiological Noise Amplification in Accelerated and Segmented EPI Acquisitions

Christina Triantafyllou[1,2], Jonathan R Polimeni[2], Jennifer A McNab[2], Thomas Witzel[2], and Lawrence L Wald[2,3]

[1]*A.A. Martinos Imaging Center, McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge, MA, United States,* [2]*A.A. Martinos Center for Biomedical Imaging, Department of Radiology, MGH, Charlestown, MA, United States,* [3]*Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA, United States*

Introduction: Recent technological advances in array coils and higher field strengths have enabled highly parallel detection of functional MRI time-series, allowing exploration of sub-millimeter spatial resolutions with decreased susceptibility distortions in EPI acquisitions. Shorter readout times, less T_2* blurring effects and high resolutions can be achieved either by using accelerated imaging or multi-shot segmented EPI. In parallel imaging, thermal noise increases by $g\sqrt{R}$ (where g is the g-factor and R is acceleration). Multi-shot EPI acquisitions also reduce distortion (by factor of S, the number of shots), but with increased physiological fluctuations, which usually dominate the time-series noise [1-3], as well as increased image repetition time. In this study, we compare acquisitions with matched EPI distortion; R fold accelerated (GRAPPA) single-shot and non-accelerated mutli-shot (S shots) EPI acquisitions with matched effective echo spacing (i.e. R=S). We use time-series Signal-to-Noise Ratio (tSNR) as the metric for BOLD detection, since BOLD CNR is the product of ΔR_2*, TE and tSNR. Our findings demonstrate that in both thermal and physiological noise dominated acquisitions, when the temporal sampling interval is matched, by temporally smoothing the single-shot time-series, the single-shot accelerated time-series result in higher tSNR. But if the fixed duration scan can afford reduced temporal resolution (sampling interval not matched), then the slower multi-shot strategy provides slightly higher tSNR than the distortion matched single-shot acquisition.

Methods: Three subjects were studied on a 3T Siemens system, (MAGNETOM Trio, a Tim system, Siemens Healthcare, Erlangen, Germany) with the product 32Ch brain array receive head coil. Resting-state 2D gradient echo EPI measurements at 2mm and 3mm isotropic resolution were obtained using two different sequences: i) single-shot EPI with GRAPPA acceleration and ii) multi-shot segmented EPI. Other imaging parameters were: TE/α=30ms/90^o and 25 slices parallel to the AC-PC. In all cases, the TR was set to 2s to achieve equal steady state magnetization in all cases, while in the segmented acquisitions the "image repetition time" increased with the number of segments. The degree of acceleration (R) and number of shots (S) varied across different runs between 1, 2, 3 and 4. For the single-shot accelerated data, the number of time-points (N_{tp}) kept constant (240), while in the multi-shot experiment the N_{tp} varied (N_{tp}=240, 120, 80 and 60 time-points for 1, 2, 3 and 4 segments, respectively) to preserve the scan time of 8 min 08 s amongst acquisitions. Array data was combined with the root Sum-of-Squares method.

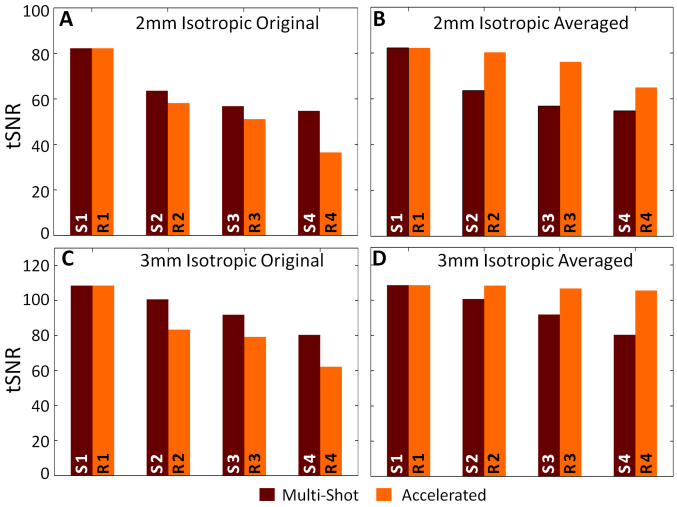

Fig. 1: tSNR measurements as a function of acquisition scheme at two isotropic resolutions. (A), (C) truncated and (B), (D) temporally averaged accelerated single-shot time-series matching the temporal sampling interval of multi-shot acquisition. R and S indicate the acceleration and segmented factors, respectively.

After motion and drift correction, time-course SNR (tSNR) maps were generated from the mean pixel value across time-points divided by their temporal standard deviation and evaluated in gray matter ROIs for each resolution. The tSNR of the *Original* two 8 minute acquisitions were compared for runs with equal susceptibility distortion (R=S) even though the two methods have a different number of time-points for the 8min run. We also compared the slower multi-shot acquisition to a *Block-Averaged* version of the faster single-shot time-series. To yield a matched number of time-points the Block size was set to S. Additionally, a *Temporally Sub-Sampled* version of the single-shot time-series was created by retaining only every Sth time-point in the faster single-shot time-series.

Results and Discussion: Figure 1 shows the tSNR comparison for the *Original* 8min acquisitions and for the *Block-Averaged* case. At both resolutions, the *Original* 8min time-series (not matched in total number of time-points), the multi-shot resulted in a slightly higher tSNR compared to accelerated single-shot data (Fig. 1A, 1C). When the faster single-shot time-series was *Block-Averaged* (Fig. 1B) to match the temporal resolution and total number of time-points, then the single-shot sequence provdied higher tSNR. Block averaging did not provide the full factor of $\sqrt{R}$, at either resolution, likely due to temporal correlations in the physiological noise . At 3mm data the Block- Averaging increased the tSNR such that it was equivalent across acceleration factors (Fig. 1D) indicating that the physiological noise dominated whereas in the 2mm data the effects of Block-Averaging was more consistent with significant thermal noise [2]. These findings suggest that accelerated acquisitions would be preferable for physiological noise dominated scan protocols. In the case of *Temporal Subsampling*, the results were very similar to the *Original* time-series tSNRs.

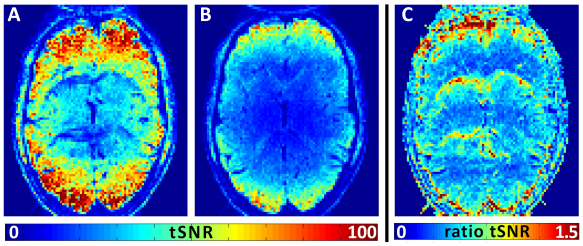

Fig. 2: Representative tSNR maps for (A) multi-shot EPI, S=4 (B) single-shot EPI, R=4 and their corresponding ratio map (C).

Figure 2 shows representative tSNR maps at 2 mm isotropic resolution, for (a) non-accelerated multi-shot (S=4), (b) single-shot accelerated (R=4) EPI, and (c) their corresponding ratio. The spatial variation of the physiological instability in the multi-shot EPI is apparent, which could potentially limit the use of multi-shot EPI acquisitions for functional imaging in areas other than the cortical gray matter.

Conclusion: Our findings demonstrate that when the faster single-shot accelerated acquisition is temporally filtered to match the temporal resolution of the slower multi-shot acquisition, then the single-shot sequence provides higher tSNR. Comparison of the effect of temporal smoothing and temporal sub-sampling showed that significant temporal correlation exist in the time-series with the lower resolution data more temporally correlated. This is consistant with a higher physiological noise content at the lower spatial resolution.

References: [1] Krueger G, *et al.* MRM, 46:631-7, 2001. [2] Triantafyllou C, *et al.* NeuroImage, 26(1):243-50, 2005. [3] Triantafyllou C, *et al.* NeuroImage, 55:597-606, 2011.