Evaluation of Readout-segmented EPI for use in fMRI at 7T

Ryan K Robison[1,2] and Allen T Newton[2,3]

[1]*Philips Healthcare, Nashville, Tennessee, United States,* [2]*Vanderbilt University Institute of Imaging Science, Vanderbilt University, Nashville, Tennessee, United States,* [3]*Monroe Carell Jr. Children's Hospital at Vanderbilt, Nashville, Tennessee, United States*

TARGET AUDIENCE: This work is intended for those interested in methodological developments in dynamic and functional MRI.

PURPOSE: Most high resolution 7T fMRI studies make use of single-shot EPI (SS-EPI), despite its inherent sensitivity to off-resonance and T2* decay. Multi-shot EPI accommodates the acquisition of high-resolution data while mitigating the effects of off-resonance and T2* decay at the cost of temporal instability. In interleaved multi-shot EPI (MS-EPI), shot-to-shot signal errors are periodic in the phase encode direction with a period of $1/Nshot$, resulting in ghosting artifacts at locations of $\pm FOV/Nshot$. These ghosting artifacts change dynamically with the signal errors, and may be strong enough to overwhelm the BOLD signal differences. Readout-segmented EPI (RS-EPI) is an alternative multi-shot EPI technique [1-3]. Time-varying signal errors still occur between shots in RS-EPI, but they are not periodic in the phase encode direction. For an odd number of shots, RS-EPI covers the center of k-space—where the majority of the signal energy is concentrated—in a single shot. Thus, the changes in signal between shots in RS-EPI are smaller in magnitude and less coherent compared to interleaved multi-shot EPI. It is proposed that RS-EPI can provide improved dynamic stability in comparison to MS-EPI for an equivalent number of shots, while also producing less distortion as compared to SS-EPI.

METHODS: The effects of temporally varying signal errors were simulated from a static image (figure 1a) over 100 time points for MS-EPI and RS-EPI by applying zero-order phase errors shot-by-shot. The simulated phase errors were varied sinusoidally with time, as might be expected for respiration [4]. In-vivo dynamic SS-EPI, three-shot MS-EPI, and three-shot RS-EPI data were acquired on a Philips Achieva 7T system (time per volume = 1.8s, TE = 25ms). The TR per shot for MS-EPI and RS-EPI was 600ms. All data were reconstructed off-line.

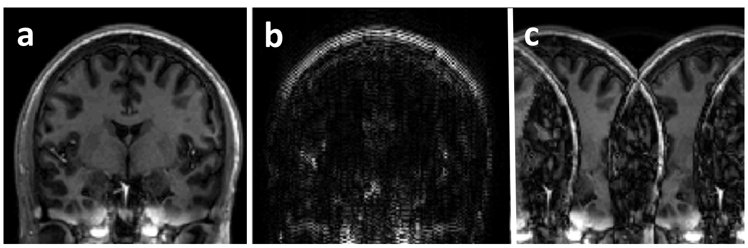

Figure 1: Temporal deviation patterns simulated by applying phase variations to the static image shown in (a) for b) RS-EPI and c) MS-EPI. In b-c, the image amplitude was scaled by ~40x. The standard deviation patterns manifest as FOV/Nshot ghosts in interleaved multi-shot EPI and around sharp image features in readout-segmented EPI.

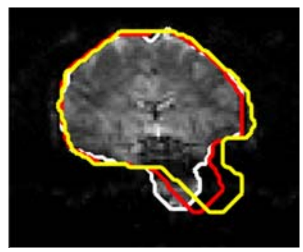

Figure 2: Example of geometric distortion experienced by a SS-EPI (yellow), RS-EPI (red), and MS-EPI (white) acquisition.

RESULTS: The effects of the simulated phase errors are shown in figure 1(b-c). Maps were calculated from the simulated data by taking the standard deviation over time. The strength and location of these artifacts is an indication of their effect on the TSNR of the dynamic series. Figure 2 overlays the image geometry for a single slice from each of the acquisitions on top of the reconstructed image for the corresponding slice from the MS-EPI case. The higher phase-encoding bandwidth of RS-EPI and MS-EPI provides a reduction in geometric distortion when compared to SS-EPI. Interleaved multi-shot EPI has the shortest gradient echo train and provides the best geometric fidelity. Temporal SNR (TSNR) maps were also calculated for each of the acquisitions for the same slice as shown in figure 3. These maps further support the postulated improvement in temporal stability for RS-EPI, as compared to MS-EPI. The single-shot case has the highest TSNR, but the RS-EPI case produces much higher and more consistent TSNR than MS-EPI.

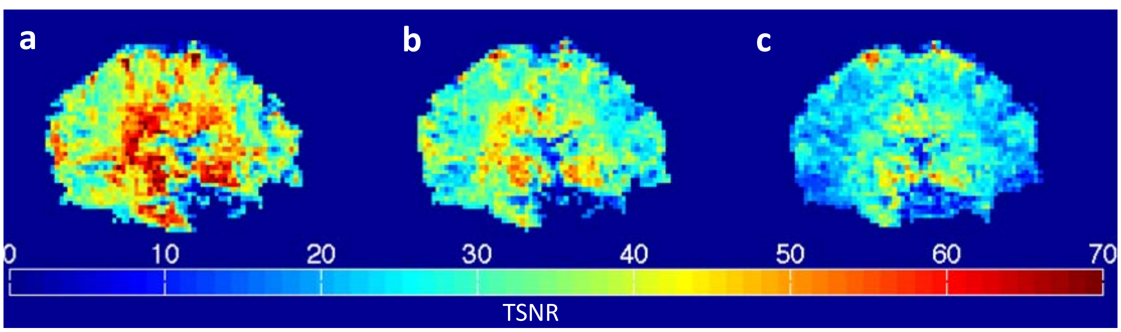

Figure 3: Temporal SNR maps over 100 time points for a) SS-EPI (max/mean TSNR= 81/39); b) RS-EPI (max/mean TSNR = 69/32); and c) MS-EPI (max/mean TSNR = 62/25). Figures were masked to suppress background noise.

DISCUSSION & CONCLUSION: Simulated and in-vivo results each demonstrate improved temporal stability for RS-EPI, as compared to MS-EPI. Furthermore, figure 2 indicates that RS-EPI provides reduced geometric distortion compared to single-shot EPI. As suggested by these results, RS-EPI provides a trade-off between temporal stability and distortions. RS-EPI should be considered for use in fMRI experiments in which an SS-EPI acquisition will have unacceptable levels of geometric distortion or T2* blurring and signal loss.

REFERENCES: **[1]** Holdsworth SJ et al. *Eur J Radiol.*2008; 65: 36-46. **[2]** Porter DA et al. *MRM* 2009; 62: 468-75. **[3]** Heidemen RM et al. *MRM* 2010; 64: 9-14. **[4]** van Gelderen P et al. *MRM* 2007; 57: 362-368.