THE EFFECT OF CARDIAC SYNCHRONIZATION ON THE TEMPORAL CHARACTERISTICS OF 3D SSFP AND 3D SGPR

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Introduction In comparison to conventional 2D EPI, 3D acquisitions with short readouts have some favourable properties, such as 1) high signal-to-noise, 2) low distortion, and 3) the ability to acquire images at isotropic resolution. These characteristics make steady-state free precession (SSFP) and spoiled gradient echo (SPGR) attractive candidates for high resolution FMRI of subcortical structures, where B_0 homogeneity is reduced compared to cortical regions [1]. Unfortunately, 3D acquisitions suffer from temporal instabilities in these areas, which are predominantly caused by pulsatile flow of blood and CSF. We previously presented simulations suggesting that synchronizing the readout to the cardiac cycle in real-time could improve the temporal stability in the brainstem [2]. Here, we present data acquired with our proposed real-time synchronization and image reconstruction technique, and compare the temporal stability of SSFP and SPGR data in different brain regions.

Theory In multi-shot acquisitions, pulsatile blood and CSF introduce abrupt signal variations across k-space, creating time-varying ghosts and blurring. Synchronizing the ordering of k-space segments in real time to the cardiac cycle improves the temporal stability by enforcing smooth signal variations across k-space [3]. In another abstract presented by our group we propose a method that synchronizes a 3D stack-of-segmented EPI readout to the cardiac cycle (Fig 1). A constant volume acquisition rate is ensured by replacing problematic data with parallel imaging techniques, making this method compatible with standard FMRI paradigms and analysis.

Experiments Passband SSFP and SGPR data were acquired in 4 healthy volunteers on a 3T Siemens Trio scanner using a 12-channel head coil. 3D time-series were acquired with and without the proposed real-time cardiac synchronized readout. The SPGR acquisitions were identical to the SSFP acquisitions, but included gradient spoiling (2cycl/vox) and RF spoiling (117°). Scan parameters for all four acquisitions were as follows: α=30°, T_R/T_E=12/6 ms, FOV=192x192x48, Matrix=96x96x24, 1860 Hz/px, 8 lines per TR, Tvol=3.5s, 60 volumes. The shim volume was targeted over the brainstem, a target sub-cortical region that is both neuroscientifically important and technically challenging for imaging. For reconstruction of the synchronized data sets, a custom 3D GRAPPA kernel was used.

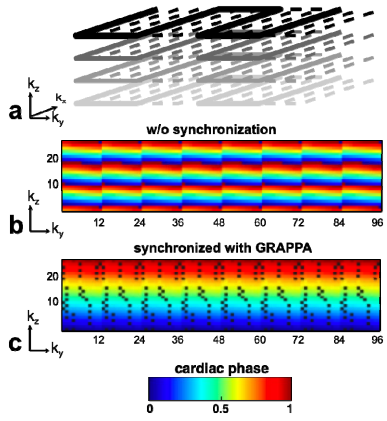

Figure 1: 3D stack-of-segmented EPI readout (a), and ky-kz views of the readout showing the cardiac phase at which each readout line is acquired without (b) and with (c) cardiac synchronization.

Results When SSFP data is acquired without synchronization, the brainstem shows heavily reduced tSNR compared to other brain regions (Fig. 2, Fig. 3a). Synchronization results in a localised improvement of tSNR in the brainstem of at least 40% in all subjects tested (Fig 3b). For other brain regions the tSNR is slightly reduced (up to -10%). In SPGR the reduced tSNR is not just localised to the brainstem, but other deep sub cortical structures such as the hippocampus and thalamus are affected as well (Fig. 2, Fig. 3c). The improvement caused by synchronization is more spatially extended than for SSFP. All ROIs tested show an improvement in tSNR with most of the improvement achieved in the deeper brain structures (Fig. 3d).

Discussion Although a smooth cardiac function across k-space is created by synchronization, the respiratory function is effectively scrambled by reordering. The change in tSNR is therefore a tradeoff between reduced cardiac and respiratory sensitivity. In SSFP the main instabilities are caused by pulsatile CSF flow surrounding the brainstem, which are greatly reduced by synchronization. SSFP may therefore represent a good alternative for studies specifically interested in identifying brainstem activity. In SPGR the tSNR improvement extends to other subcortical structures indicating that the effects of cardiac-related physiological noise are more wide-spread spatially in SPGR compared to SSFP. Recently, several groups have re-visited the potential of 3D SPGR sequences for high-field FMRI [4]. The short T2* at high field along with the need for low-distortion sequences make this method increasingly viable. This is particularly relevant for sub-cortical structures, which require high resolution to resolve small nuclei. Our results suggest that cardiac synchronization could significantly improve this kind of acquisition.

Conclusions. We have shown that synchronizing the readout with respect to the cardiac cycle is beneficial for 3D SSFP as well as 3D SPGR acquisitions. Although SSFP showed a 1.5 fold increase of tSNR in the brainstem, a small reduction was observed in other areas of the brain. SPGR on the other hand showed a consistent increase in tSNR throughout the brain, with an average tSNR increase of 13% and 24% in the hippocampus and thalamus, respectively.

References. [1] Parrish ISMRM 2008 [2] Tijssen et al. ISMRM 2010 [3] Cho. MRI 1990 [4] Poser NIMG 2010

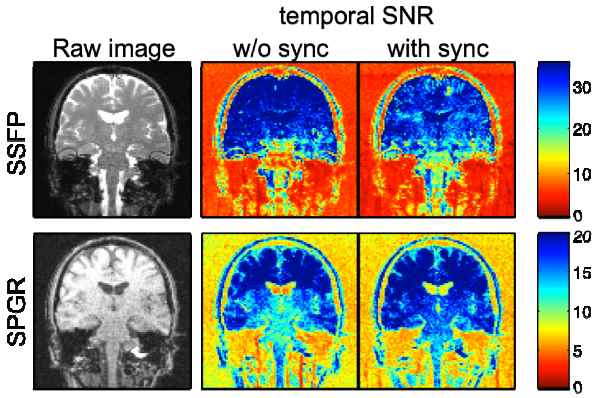

Figure 2: temporal SNR maps for SSFP (top) and SPGR (bottom). Synchronization results in a significant increase in tSNR in the brainstem (SSFP and SPGR) and other subcortical structures such as the hippocampus and thalamus (SPGR).

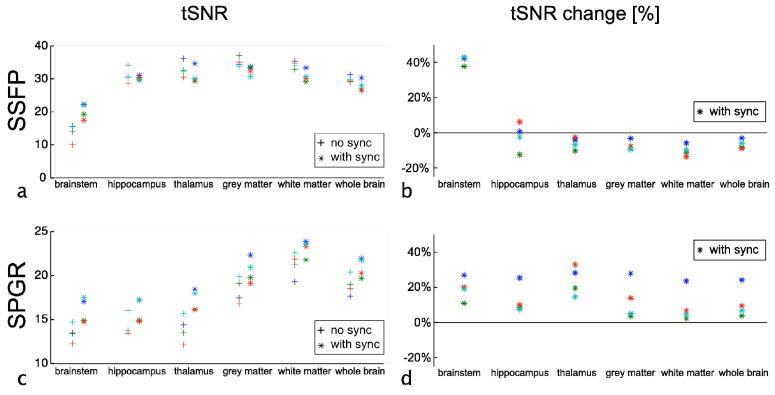

Figure 3: ROI analyses showing the relative change in tSNR relative to the non-synchronized readout for each subject. The two methods shown are: synchronized and synchronized in combination with Partial Fourier.