Application of k-t FASTER for rank-constrained acceleration of in vivo FMRI data

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Purpose A common goal of many FMRI acquisition strategies is to enable faster and more efficient sampling of temporal information. Recently, k-t FASTER (FMRI Accelerated in Space-time via Truncation of Effective Rank) was introduced as a method for accelerating FMRI data acquisition using novel matrix rank constraints in simulated data [1]. The method exploits the fact that resting FMRI data is often considered to have low intrinsic dimensionality, such that important features in the data are captured in a small number of principal or independent components (PC/ICs). This can be used to under-sample an FMRI time-series while retaining much of the important information, by simultaneously leveraging spatial and temporal structure to recover the data with non-linear reconstruction methods. We previously presented the k-t FASTER concept on retrospectively under-sampled data (simulations); here, k-t FASTER is applied to 4.27x prospectively accelerated 3D FMRI data in healthy subjects. We demonstrate high fidelity reconstructions of FMRI resting state networks (RSNs) in the absence of coil sensitivity information, relying solely on rank constraints for recovery of un-sampled k-t data points. This validates the ability of the low-rank reconstruction to retain data features salient for RSN identification at moderate acceleration factors.

Methods Six healthy subjects were imaged using a modified 3D EPI pulse sequence at 7 T. Data were acquired using a spatial matrix size of 100x98x64 (2 mm isotropic resolution) for 5 minutes at a time, with TR/TE of 65/31 ms. The 4.27x accelerated datasets were acquired by omitting 49/64 k_z planes every volume, in a pseudo-random fashion with 8 central k_z planes always sampled, and 7 outer planes randomly sampled, for a volume TR of 975 ms (304 time points). Comparison datasets of the same imaging duration were also acquired, fully sampling the k_z dimension for a volume TR of 4160 ms (72 time points). In both cases, an in-plane acceleration factor of 2 was used and recovered independently of the z-acceleration using GRAPPA [2] to achieve an appropriate TE for FMRI. For each subject, two fully-sampled (EP3D) and two under-sampled (k-t FASTER) datasets were acquired for comparison. Matrix reconstruction was performed using the same IHT+MS (Iterative Hard Thresholding with Matrix Shrinkage) algorithm [3] that was used in the original demonstration of k-t FASTER (rank 72) with the additional step of re-inserting the originally sampled points in the final k-t matrix estimate. Evaluation of the resulting datasets was performed using dual regression [4] against sets of 64 and 32 canonical RSN maps (from high-dimensional group-level ICA of a large, high quality resting FMRI dataset from the Human Connectome Project). Mixture modelling was performed to produce null-corrected z-statistic parametric maps, which were voxel-wise correlated with the original regressors (RSN Maps).

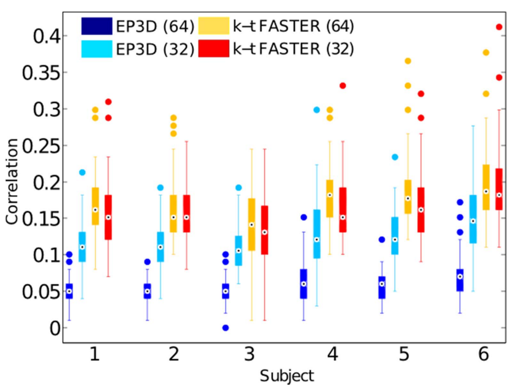

Figure 1 – Correlation box-plots for each subject in the EP3D and k-t FASTER data, using both 64 and 32 regressors.

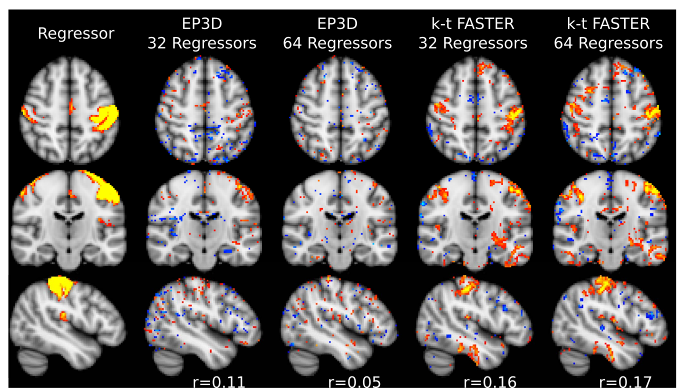

Figure 2 – Dual regression z-statistic maps from a single subject showing the left somatosensory network, representative of the "average case". Maps are shown at $|z|>2$.

Results Figure 1 shows correlation values for all 6 subjects in both sampling conditions for the 64- and 32-regressor sets. In each case, the k-t FASTER data show better correlation with the canonical regressor RSNs ($p < 0.001$ FWE), which reflects the advantages of faster temporal sampling. The negligible difference between the 32- and 64-regressor results ($p > 0.05$ FWE) indicates that the k-t FASTER data has sufficient degrees of freedom for regression against 64 maps, despite the rank-72 constraint during reconstruction. It should be noted that the correlations are relatively low due to the inherent variability in single-subject RSNs, the short sampling durations examined, and the presence of noise or artefacts. The values, however, are comparable to those obtained using single-subject analyses on high-quality fully-sampled data (not shown). Figure 2 shows z-statistic maps for a single subject in an RSN representative of the "average case".

Discussion These results demonstrate the feasibility of using only low-rank constraints for recovery of under-sampled FMRI data *in vivo*, compared to an un-accelerated 3D EPI acquisition. The results from the 64 vs. 32 regressor sets indicate that more temporal information is available using k-t FASTER than the standard EP3D acquisition, despite equivalent sampling periods. While acceleration using rank constraints is limited by intrinsic data structure, the synergy with well-established analysis methods (ICA/PCA) that exploit the same structure make it a very powerful approach compared to traditional acceleration methods that ignore the time dimension. Future work will explore FMRI acceleration incorporating rank constraints in conjunction with other acceleration methods, including sparsity [4] and/or multi-coil information [5], for improved reconstruction fidelity and higher acceleration factors. Joint multi-coil reconstructions and high acceleration ($R > 4$) will enable higher efficiency FMRI with respect to capturing spatio-temporal information pertinent to RSN identification.

References 1. Chiew et al., ISMRM 2013 #3274 2. Griswold et al., MRM 2002; 47(6):1202-10 3. Chiew et al., ISMRM 2013 #3792 [4] Candes et al., Journal of ACM 2009; 58(1):1-37 [5] Trzasko et al., ISMRM 2013 #0603