High SNR and High-Resolution fMRI using 3D OSSI and Tensor Model Reconstruction

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Introduction

Oscillating Steady-State Imaging (OSSI)

- a new fMRI acquisition approach, exploits a large and oscillating signal
- provides inherent T_2^*-weighting at time of excitation

Compared to standard fMRI (GRE)

- can provide 2 times higher SNR, well-suited for high-resolution fMRI

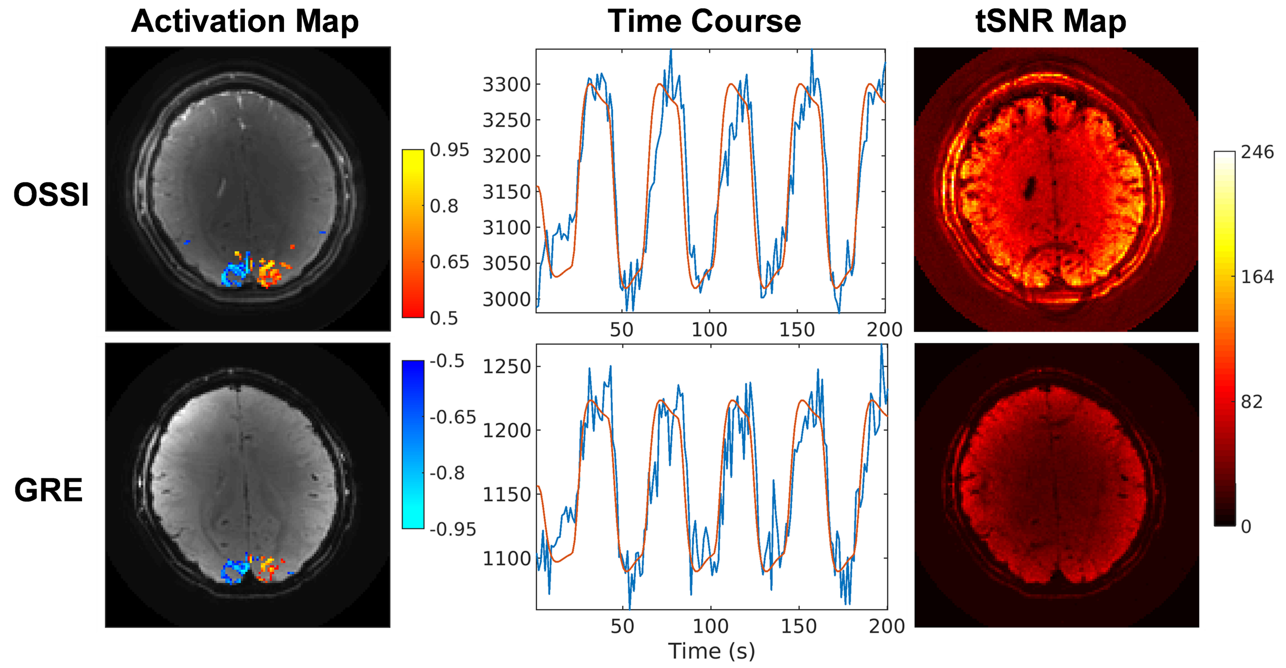

Figure: OSSI fMRI compared to GRE fMRI.

Challenges for high-resolution fMRI

- n_c time points in an oscillation slows acquisition by this factor
- short TR for each image limits k-space extent

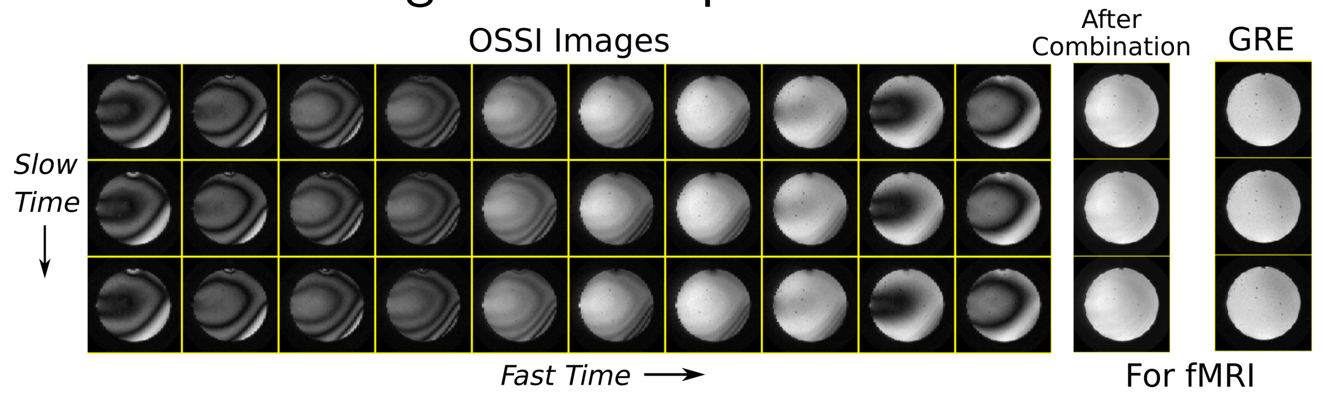

Figure: OSSI images with periodic oscillation pattern ($n_c = 10$).

Patch-Tensor Low-Rank Model

High-dimensional and local spatial-temporal low-rankness

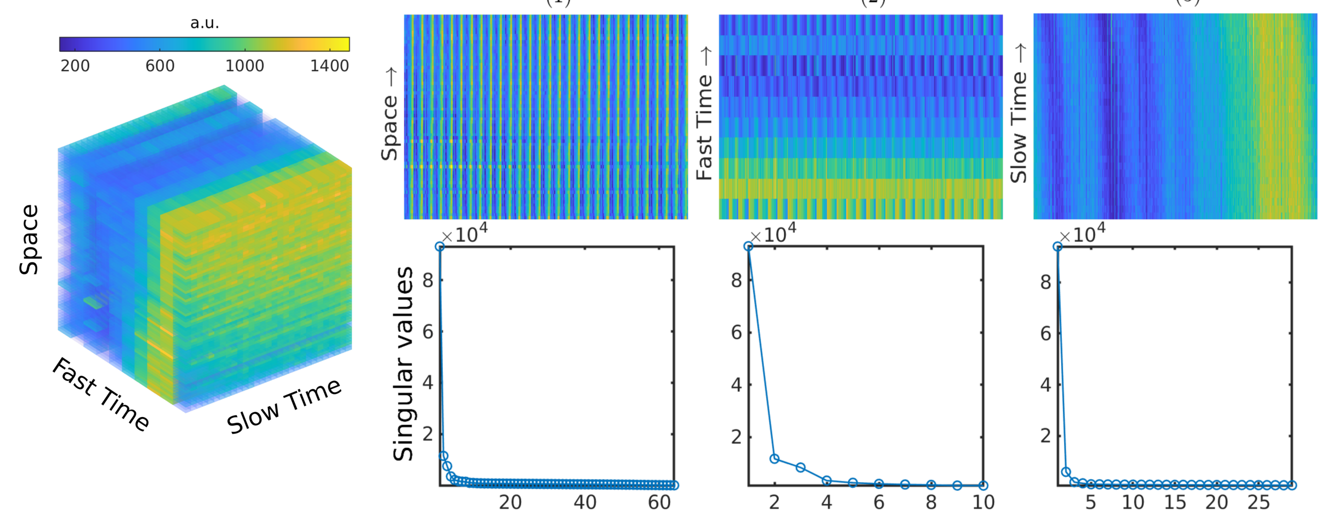

Figure: A 3D patch-tensor unfolds to 3 low-rank matrices.

- patch tensor dimensions: vectorized space × fast time × slow time
- low-rank constraint on all the matrix unfoldings of a tensor

Reconstruction Problem

$$\underset{\mathbf{X}}{\text{minimize}}\ \frac{1}{2}\|\mathcal{A}(\mathbf{X}) - \mathbf{y}\|_2^2 + \sum_{\mathcal{P}} \sum_{i=1}^{3} \lambda_i \|\mathcal{P}(\mathbf{X})_{(i)}\|_*$$

- $\mathbf{X} \in \mathbb{C}^{x \times y \times n_c \times t}$ denotes the OSSI fMRI images to be recovered,
- $\mathcal{A}(\cdot)$ represents the MRI physics, $\mathbf{y}$ contains sparse k-space data,
- $\mathcal{P}(\cdot)$ partitions and reshapes its input into locally low-rank patch-tensors.

3D Sparse Acquisition

Variable-density spirals with good temporal incoherence

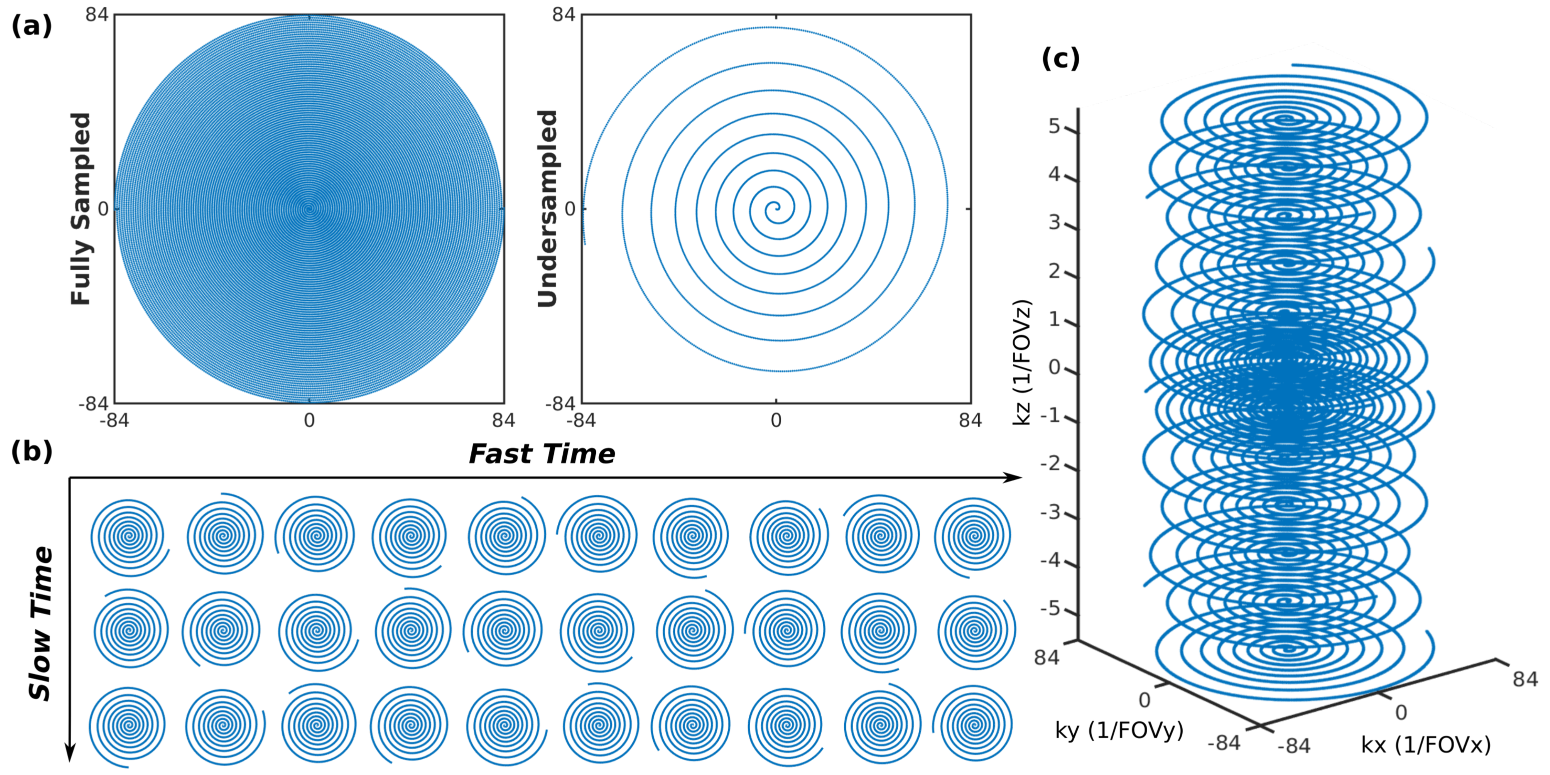

Figure: (a) In-plane VD spiral with 12-fold acceleration. (b) Incoherent rotations in both fast time and slow time. (c) 3D prospectively undersampling with increased sampling density in central k_z.

- acquires less than **10%** of the fully sampled k-space data (R = 10)

fMRI Experiment

- 3T GE MR750 scanner, 32-channel head coil, 3D oblique slab
- OSSI acquisition: TR/TE = 15/10.3 ms, $n_c = 10$, FA = 10°
- fMRI task: left vs. right reversing-checkerboard visual stimulus
- compared to the standard mutli-slice Ernst-angle GRE fMRI at TE = 30 ms with matched spatial-temporal resolution

Summary: High-resolution 3D OSSI for fMRI

- **10**-fold acceleration, **1.3 mm** spatial resolution, **2.1 s** volume TR
- **2** times more functional activation and **2** times higher temporal SNR

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Prospectively Undersampled Results

2D spatial resolution 1.3x1.3x2.5 mm^3, volume TR 150 ms

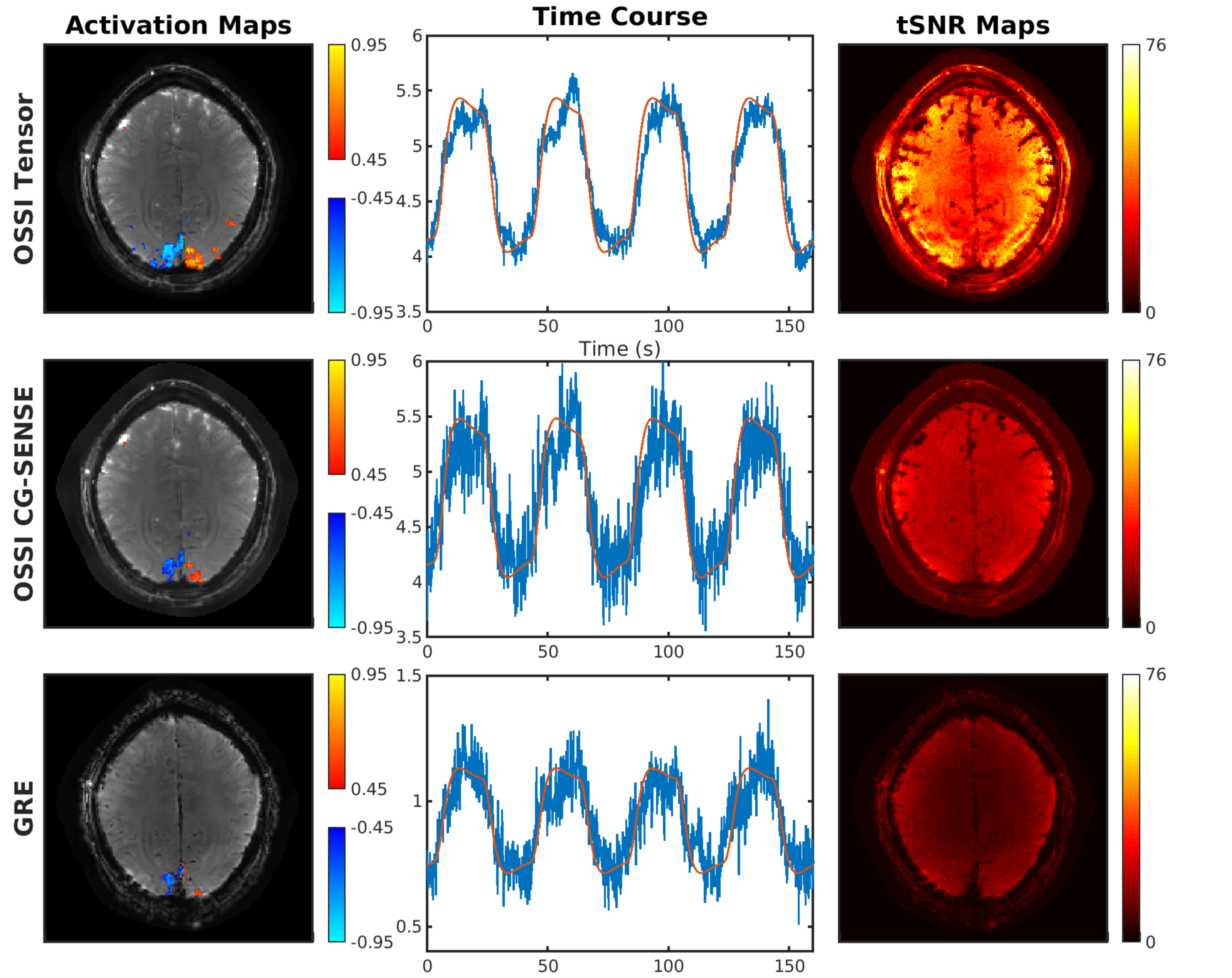

Figure: Activation maps, time courses, and temporal SNR maps of the proposed approach, CG-SENSE reconstruction, and GRE fMRI.

3D spatial resolution 1.3x1.3x2.5 mm^3, volume TR 2.1 s (12 slices)

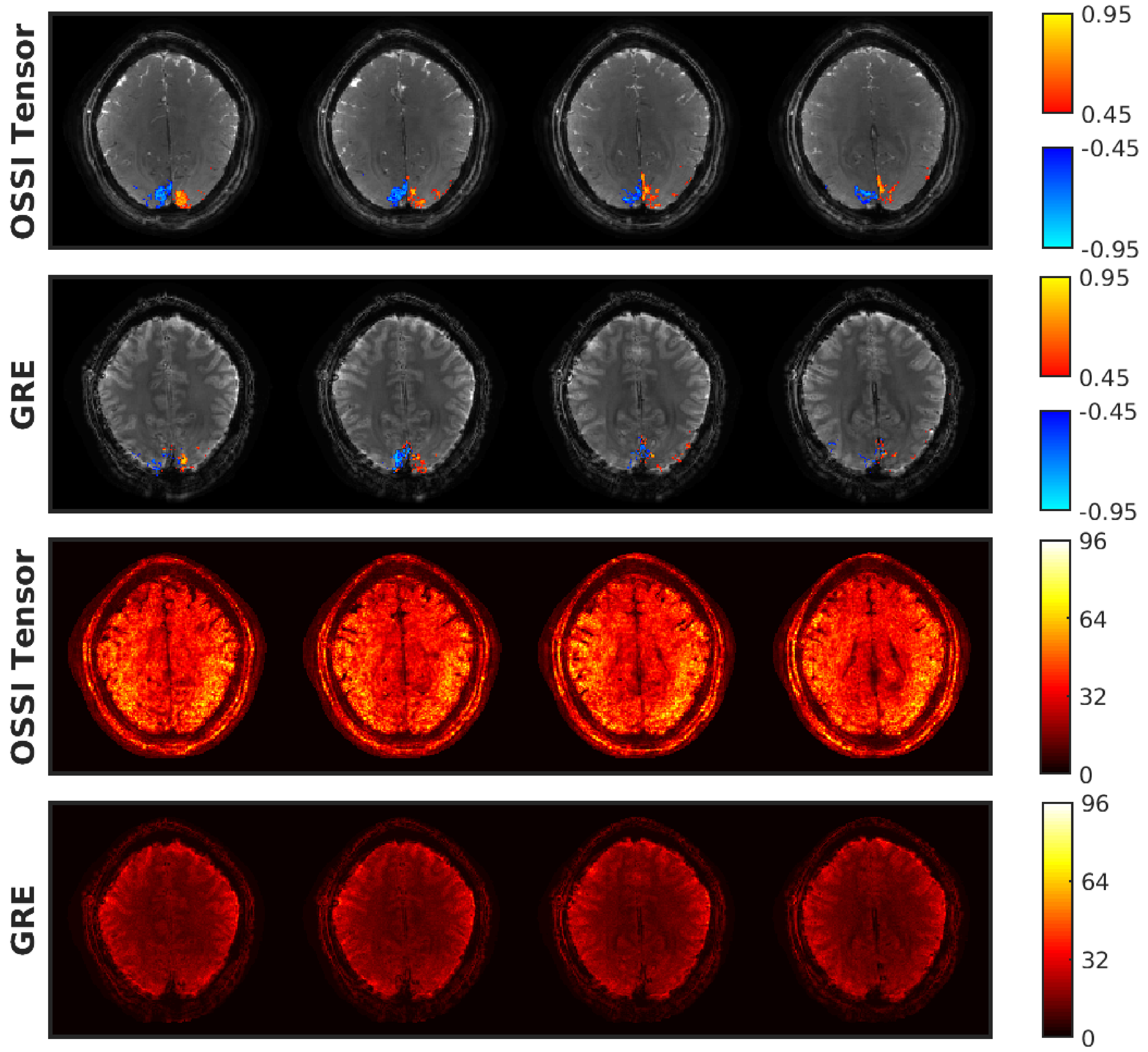

Figure: 3D OSSI compared to multi-slice 2D GRE fMRI.