A functionally time-resolved reconstruction technique for high-resolution fMRI.

Poster 2223

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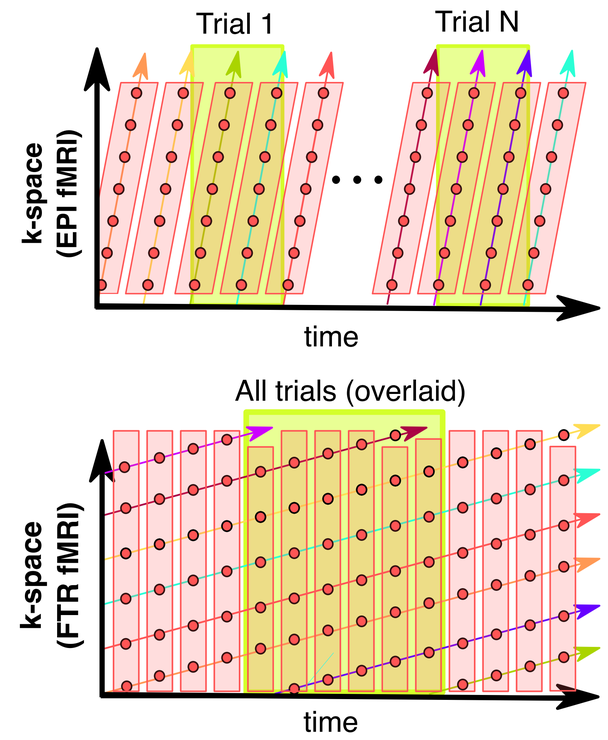
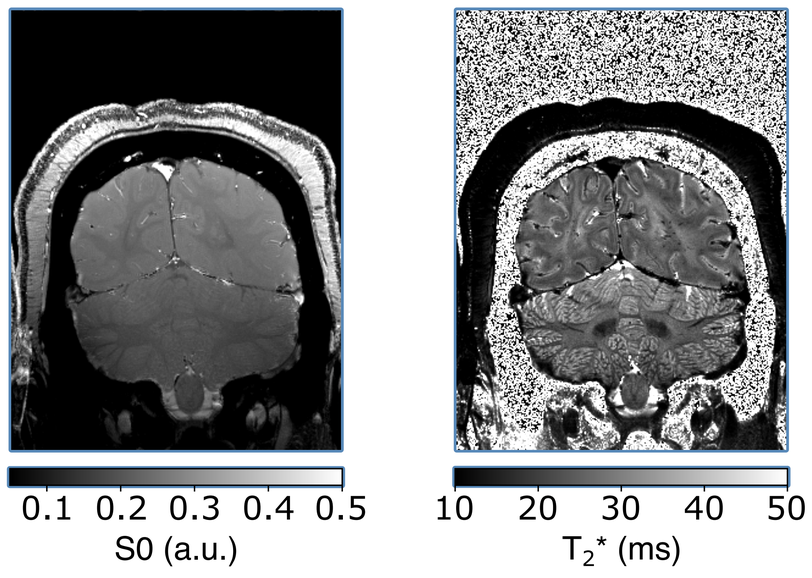
Introduction

- Sub-millimeter fMRI is a promising method to probe mesoscopic brain responses[1,2], yet is currently too coarse to sample from individual human columns and layers.
- High-resolution fMRI using EPI readouts and BOLD contrast suffer from spatial distortions and T2* blurring due to long readout trains[3].
- Here, we build on time resolved methods[4,5] to incorporate neuroscientific experimental designs into fMRI reconstruction to times-resolve data from a multi-echo, multi-shot gradient echo sequence.
- Our method, ***functionally time-resolved fMRI*** (fTR), can achieve very high spatial resolution (here, 0.5 mm) with multiple (6) echoes without sacrificing temporal resolution (here, 0.5 s).

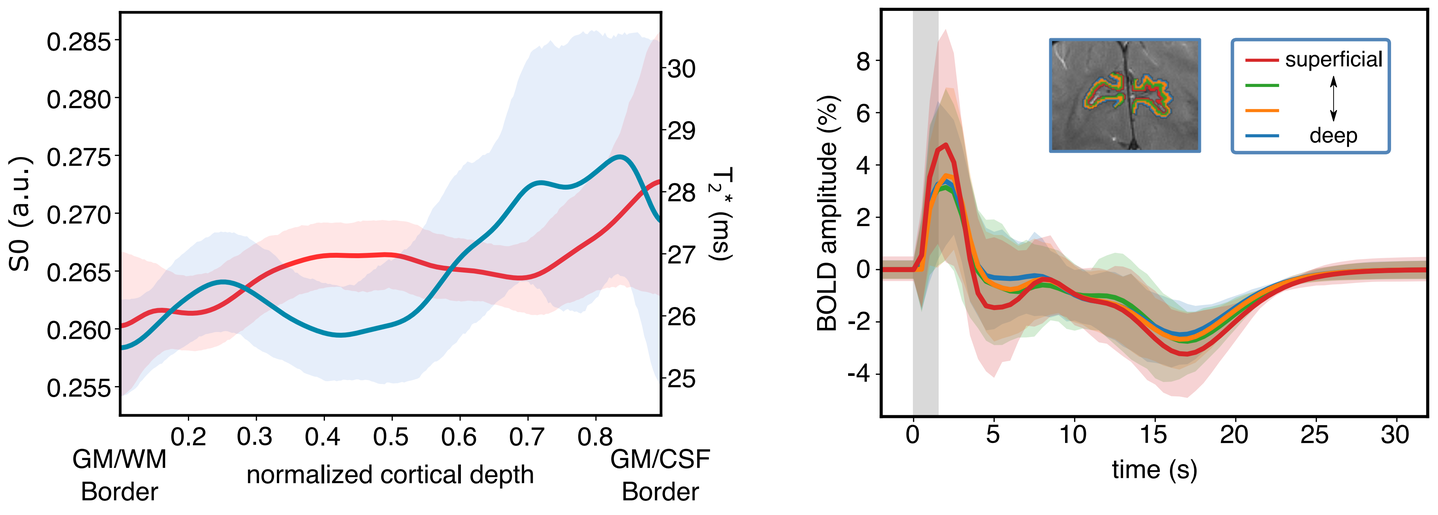


Left: Experimental and k-space acquisition timelines are shown as concurrent processes affecting MRI image formation. **Right (upper):** In a typical fMRI experiment, k-space is sampled (colored arrows) as quickly as possible to form multiple images (red boxes) that form an image time course. Thus reconstruction timelines are anchored to the beginning of the experiment. **Right (lower):** In *functionally time-resolved imaging*, all experimental trials are overlaid (green box) in order to fill k-space with a slower (but high-resolution) trajectory. This means that k-space data for each reconstructed image come from different times in the experiment, but reconstructed timelines are anchored to a neuronal event of interest.

Results



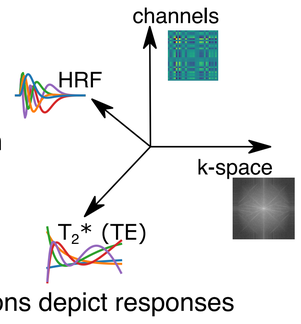
Reconstructed images. Multi-echo data are used to fit high-resolution (0.5 mm) S0 and T_2* decay time parameters. **Left:** S0 images display good gray/white matter and CSF contrast, enabling segmentation of functional data. **Right:** T_2* images provide additional CSF and vascular contrast, as well as identification of striate cortex based on the visible Stria of Gennari.



Laminar analyses. Left: Anatomical S0 and T_2* values are plotted against normalized cortical depth values in the calcarine sulcus (see segmentation image on right). Shaded areas indicate 95% CIs on the mean laminar profile. T_2* display a characteristic dip in middle layers of striate cortex. **Right:** Functional BOLD responses (optimally combined echo data) to a 2-second flashing checkerboard stimulus (10 Hz) are shown for 4 cortical depth ROIs (see inset segmentation). The gray area indicates stimulation period and shaded colors indicate 95% CIs on individual voxel time courses. Superficial layers (red) show higher response amplitudes and larger undershoots than other cortical depths, similar to high-resolution temporal BOLD profiles seen in rodents[6].

Methods

- **Acquisition:** Three subjects' data were collected on a Siemens MAGNETOM 7T+ w/ Nova 32Rx head coil. We collected a 2D GRE sequence (TR=31 ms, TEs=[4.22, 8.38, 12.54, 16.7, 20.86, 25.02] ms (bipolar readout), res=0.5x0.5 mm, slc thickness=0.8 mm, matrix=360x270, PE=R/L, repetitions=36, no acceleration or Partial Fourier, acquisition time=5:01). Prescription was perpendicular to the Calcarine Suclus.
- **Experiment:** Participants were presented a flashing radial checkerboard (10 Hz; 2 s presentation, 15 s ISI) and were asked to fixate for the entire experiment.
- **Reconstruction:** Data were reconstructed via low-rank tensor completion[4,7] with modes for k-space, receivers, echoes and response time. Initial k-space, channel and echo subspaces were derived non-time resolved data with SVD. The time subspace was an informed 2-gamma HRF basis (derived from a PCA of 10,000 HRFs with random input parameters). The subspaces and rank-(20, 7, 3, 5) core tensor were then iteratively updated with available data until the 2-norm of the core converged. Reconstructions depict responses from -2 to 32 seconds after stimulus onset.



- **Analysis:** S0 & T2* maps were linearly fit to log-multi-echo data. These maps were used to segment gray matter of the Calcarine sulcul region and to compute cortical depth values for each voxel (to plot layerwise S0/T2* values) and 4 equivolume layers (to plot response functions) using LAYNII software[8]. 95% confidence intervals for S0/T2* values were computed via 1000 bootstrap samples (33% of voxels in each sample) of layer profiles. CIs for response functions represent the 95% bounds of individual voxel responses.

Conclusions

- Functionally time-resolved fMRI incorporates experimental designs into image reconstruction to capture high spatial and temporal resolution brain responses.
- fTR fMRI does not suffer from spatial distortions in the phase encoding direction and S0/T2* maps provide good anatomical contrast, aiding neuroscientific interpretation of experimental data.
- Future directions include applying fTR to other image contrasts[5], incorporating physiological signals into reconstructions and motion mitigation.

References

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