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3D-SPARKLING for functional MRI: A pilot study for retinotopic mapping at 7T

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Introduction:

Whole brain high isotropic spatial resolution BOLD fMRI is usually achieved with undersampled Cartesian techniques, such as segmented 3D-EPI[5] or 2D SMS-EPI. However, the acceleration factors allowed by these methods remain intrinsically constrained by the phased array coil geometry used. Compressed-sensing (CS) was introduced in Cartesian and non-Cartesian MRI as an alternative to speed up even further acquisition times[10] while preserving image quality. Recently, SPARKLING, a CS-based method, was developed for anatomical MRI[6,7]. SPARKLING readouts are multi-shot and hardware constrained trajectories that combine non-Cartesian variable density sampling with locally uniform coverage of k-space. For the first time, the prospects of using 3D-SPARKLING were studied and compared to state-of-the-art CAIPIRINHA segmented 3D-EPI.

Methods:

Three healthy volunteers were scanned at 7T using a classic retinotopic mapping paradigm: A rotating wedge with a period of 32s. The code of the experimental paradigm is available in [3].

Functional data was collected using the sequence parameters reported in Fig.1-a. Two consecutive runs were carried out for each method (3D-EPI, 3D-SPARKLING) and each participant. The order in which the sequences were run was randomized across individuals. On the one hand, B0 and external sensitivity maps for 3D-SPARKLING data were acquired using a multi-echo gradient recalled echo (GRE) sequence. These maps were used during reconstruction for multi-coil calibration and static ΔB_0 correction. On the other hand, a 15s calibration is run once at the start of each 3D-EPI sequence (be it single or multiple-repetition) to acquire sensitivity maps. B0 distortions were corrected on 3D-EPI data using the TOPUP mechanism[1].

3D-SPARKLING volumes were reconstructed independently from each other using the method published in [9] which promotes sparsity in the wavelet domain. The relevant code can be found in the pysap-mri plugin[4] of the PySAP package. Fig.1-c details the image reconstruction pipeline for 3D-SPARKLING data. The 3D-EPI data was reconstructed with a GRAPPA-based reconstruction.

Retinotopic data was analyzed using a two-session first-level GLM that included 2 paradigm-related regressors (parametric, continuous and sinusoidal), 6 motion regressors (estimated using FSL[1]), a drift regressor, and the baseline. A F-test over the two sinusoidal regressors was used to estimate the global effect of interest. To estimate the functional signal phase, $\arctan(\beta_2/\beta_1)$ was computed voxel-wise, β_1 and β_2 being the z-scores derived from a t-test over respectively the first and second sinusoidal regressor. The implementation was done through the Nilearn package[2] according to the pipeline in Fig.2. The comparison was performed visually according to the effect of interest and phase maps.

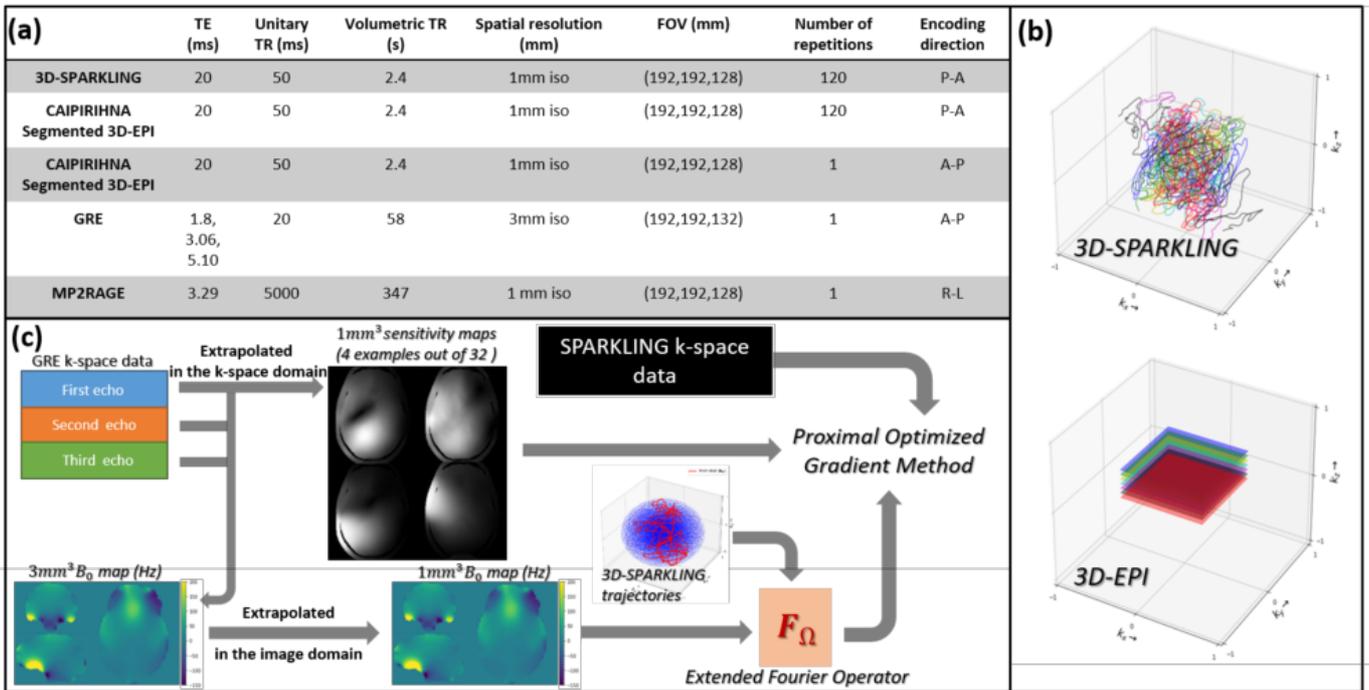


Fig.1: (a) Specifications of the different sequences used: 3D-SPARKLING and 3D-EPI were used to acquire the functional data at $1mm^3$ and $2.4s-TR_v$ resolution in P-A encoding. An additional single-repetition 3D-EPI in A-P encoding was acquired for B_0 correction on 3D-EPI data. The GRE sequence used had 3 echoes. The MP2RAGE sequence was used to acquire an anatomical T_1w scan. (b) Schematic example of seven color-coded shots from 3D-SPARKLING (top) and 3D-EPI (bottom). Shots duration is similar for both encoding schemes: $T_{obs}=26.88ms$ for 3D-SPARKLING, $T_{obs}=26.33ms$ for 3D-EPI. (c) Scheme explaining 3D-SPARKLING data reconstruction pipeline: Raw data of the first echo from the GRE sequence was used to generate the sensitivity maps whereas the full dataset was used to have an accurate estimate of the B_0 map. The B_0 map was extrapolated in the image domain to fit the spatial resolution and field-of-view of the 3D-SPARKLING fMRI scans. The sensitivity maps were extrapolated in the k-space domain to fit the same data. The acquired B_0 map was included in the definition of the extended (non-uniform) Fourier operator to define a more accurate signal model by implementing the method proposed in [8]. The Proximal Optimized Gradient Method (POGM) algorithm was used for CS MRI reconstruction.

(https://files.aievolution.com/prd/hbm2201/abstracts/abs_1788/fig1.png)

Results:

For the sake of optimal visualization, we report the results of the statistical analysis for two participants only. The observations remain valid for the third one. The effect of interest maps in Fig.2 show that the activation patterns are consistent with the visual stimulation for both methods. In addition, their z-score values are comparable. The phase maps and their orientation in Fig.2 are consistent with the mapping of the retina onto the visual cortex. This suggests that our method performs as well as the state-of-the-art in terms of significance and spatial accuracy of the recorded functional signal. We notice that the phase maps seem to be more accurate for 3D-SPARKLING.

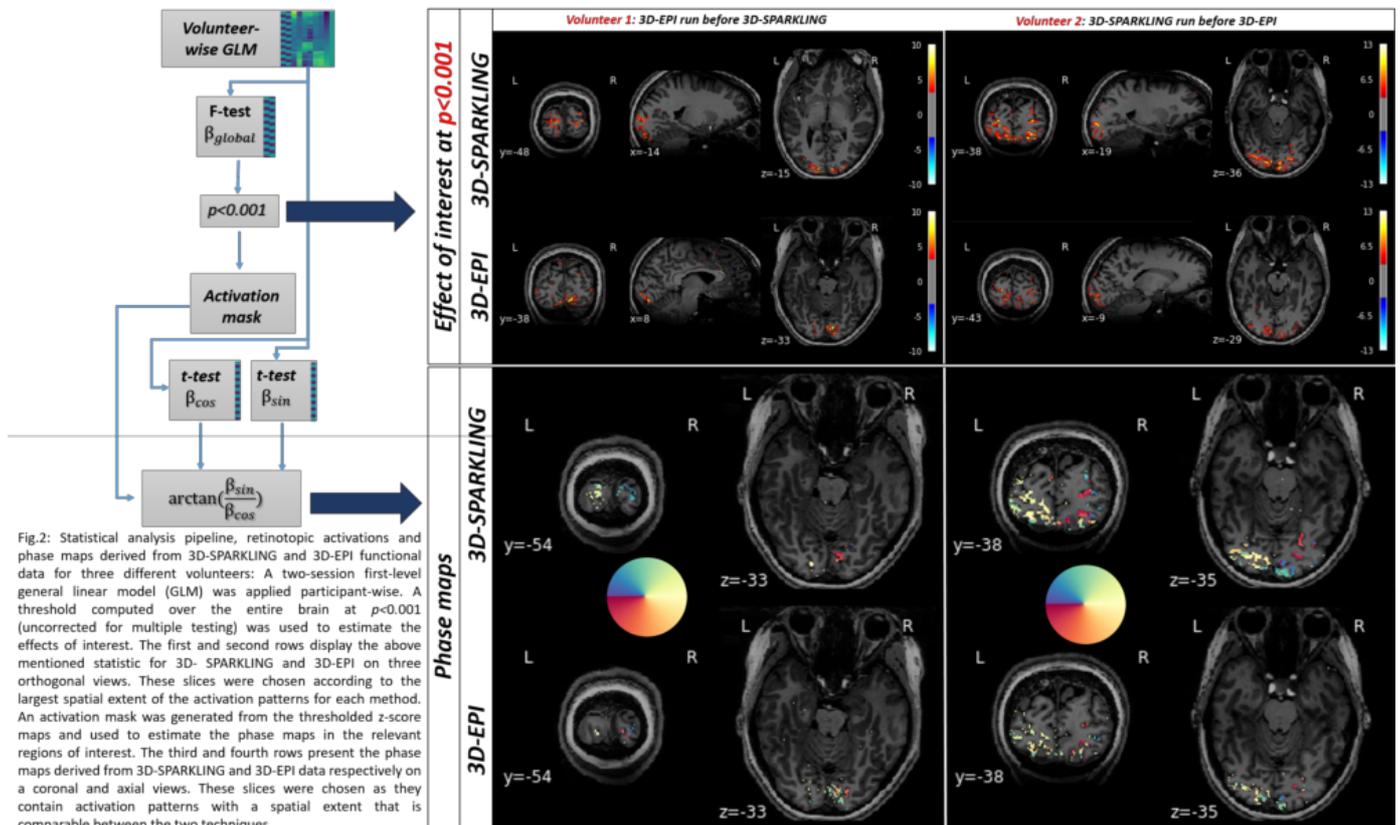


Fig.2: Statistical analysis pipeline, retinotopic activations and phase maps derived from 3D-SPARKLING and 3D-EPI functional data for three different volunteers: A two-session first-level general linear model (GLM) was applied participant-wise. A threshold computed over the entire brain at $p < 0.001$ (uncorrected for multiple testing) was used to estimate the effects of interest. The first and second rows display the above mentioned statistic for 3D- SPARKLING and 3D-EPI on three orthogonal views. These slices were chosen according to the largest spatial extent of the activation patterns for each method. An activation mask was generated from the thresholded z-score maps and used to estimate the phase maps in the relevant regions of interest. The third and fourth rows present the phase maps derived from 3D-SPARKLING and 3D-EPI data respectively on a coronal and axial views. These slices were chosen as they contain activation patterns with a spatial extent that is comparable between the two techniques.

(https://files.aievolution.com/prd/hbm2201/abstracts/abs_1788/fig22.png)

Conclusions:

3D-SPARKLING performs similarly to 3D-EPI at 1mm iso and 2.4s-TRv resolution. Consequently, it has the potential to be a suitable acquisition technique for high resolution fMRI. As each shot crosses the k-space center, 3D-SPARKLING could further enable the implementation of variable spatio-temporal resolution which is impossible with traditional Cartesian methods.

Modeling and Analysis Methods:

Activation (eg. BOLD task-fMRI) ²

Novel Imaging Acquisition Methods:

BOLD fMRI ¹

Keywords:

Other - Non-Cartesian, Compressed Sensing, Acquisition, BOLD fMRI, Retinotopic mapping, Task-based

¹²Indicates the priority used for review

My abstract is being submitted as a Software Demonstration.

No

Please indicate below if your study was a "resting state" or "task-activation" study.

Task-activation

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Yes

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Functional MRI

For human MRI, what field strength scanner do you use?

7T

Which processing packages did you use for your study?

FSL

Provide references using author date format

[1] <https://fsl.fmrib.ox.ac.uk/fsl/fslwiki>

[2] <https://nilearn.github.io/stable/index.html>

[3] https://github.com/hbp-brain-charting/public_protocols

[4] https://github.com/CEA_COSMIC/pysap-mri

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