The Origins of fMRI Contrast in SPEN Imaging at Ultra High Magnetic Fields

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BACKGROUND

We explore the features of spatiotemporal encoding (SPEN) in fMRI.

- SPEN is a new single-scan imaging scheme providing an alternative tool for fMRI, which is based on spatial- instead of frequency-encoding using frequency-swept (chirped) pulses [1] (Fig 1) .

Advantages of SPEN over EPI at ultrahigh field :

- Higher immunity to B_0-inhomogeneities and to chemical-shift offsets [2].
- Can be operated in fully refocused mode vis-à-vis T2* and/or T2 effects [2, 3, 4].

Our investigation on activation detected by SPEN fMRI;

- As function of field strength: at preclinical high (7T) and ultra-high (17.2T) magnetic fields
- Obtaining artifact-free rat brain images with high spatial resolution.
- Modulating the T2*-weighted contribution with fully T2*-refocused (variant where each readout event coincides with its own TE, thereby all T2* contributions being absent) and non-fully-refocused acquisitions.
- Monitoring modulations imposed by T1 effect s (in-flow) with field strength and TR.

MATERIALS & METHODS

- 2D SPEN images were obtained for 10 male Wistar rats at 17.2T and 7T on Bruker Avance III scanners using custom-written sequences.
- Anesthesia protocol: medetomidine the initial dose of 110 µg/kg was followed, after 20 minutes, by administration of a continuous injection, gradually increasing from 100 µg/kg/h to 300 µg/kg/h within a 2-hour period;
- Electric stimuli: pulse duration 0.3 ms, frequency 7 Hz, current intensity 2.3mA.
- **Stimulation:** Block-design paradigm consisting of 5 blocks (30 s rest, 30 s forepaw electrical stimulation, separated with 10min rest between runs) (Fig 2)
- **Acquisition parameters**:
  - FOV: 2 cm x 2 cm, matrix size 100 x 100, slice thickness 1.2 mm, BW 400 kHz at 17.2T, 357 kHz at 7T.
  - GE EPI parameters: TE = 11 ms, TR = 1500 ms;
  - SPEN parameters: T_{acq} = 25ms, $T_{exc,full\text{-}refocusing}$ = 25ms, $T_{exc,non\text{-}refocused}$ = 5ms.
  - Slices: 3 coronal slices for EPI, including the primary and secondary somatosensory cortex. The most activated slice was choosen for 2D SPEN acquisition.
- **Post processing** :
  - In-house Matlab image-reconstruction algorithms based on super-resolution (SR) principles [5];
  - Statistical analyses: SPM 8 (slice-timing, motion correction and spatial smoothing, p<0.005)

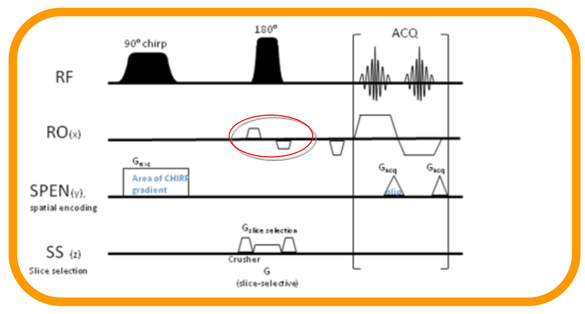

Figure 1. Spatio-tempral encoding (SPEN) single-scan 2D sequence, obtaining with spatial encoding and CHIRP pulse

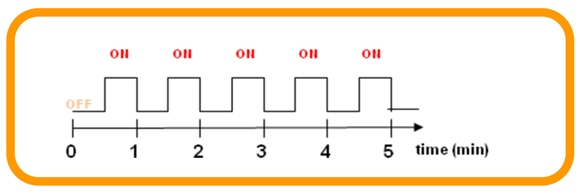

Figure 2. Stimulation paradigm

RESULTS

•At 17.2T: Fully refocused SPEN (TR = 1.5s): strong localized activation maps with good t-score levels (Fig. 3b).

•At 17.2T: Increasing TR from 1.5 s to 3 s: activation decreases (Fig. 3c).

•At 7T: the fMRI contrast in the fully refocused SPEN acquisitions decreases with field : For TR = 1.5 s the t-scores for SPEN were approximately three times smaller than for GE EPI.

•Switching from a fully T2*-refocused SPEN sequence, where T_{exc} = T_{acq}, to a non-refocused condition: classical T2*-driven BOLD contrast reinstated in SPEN, with very similar activation maps as in GE EPI(Fig 4c)

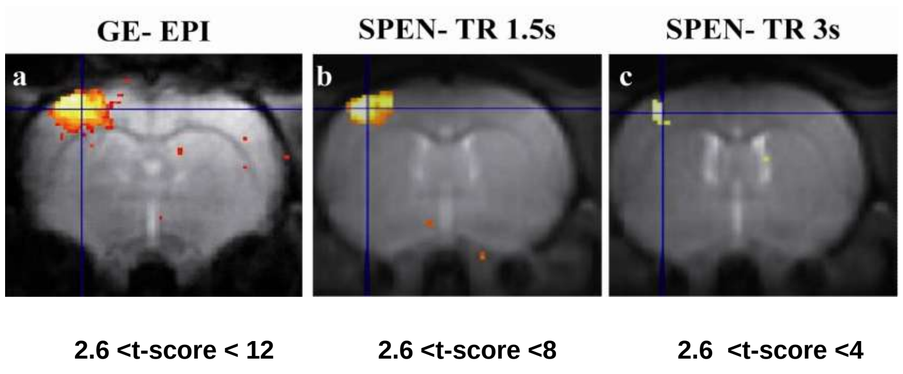

Figure 3: Comparison between GE EPI and SPEN fMRI maps recorded at 17.2 T. (a) GE- EPI; (b) fully T2*-refocused SPEN,TR 1.5s ;(c) fully T2*-refocused SPEN,TR 3s.

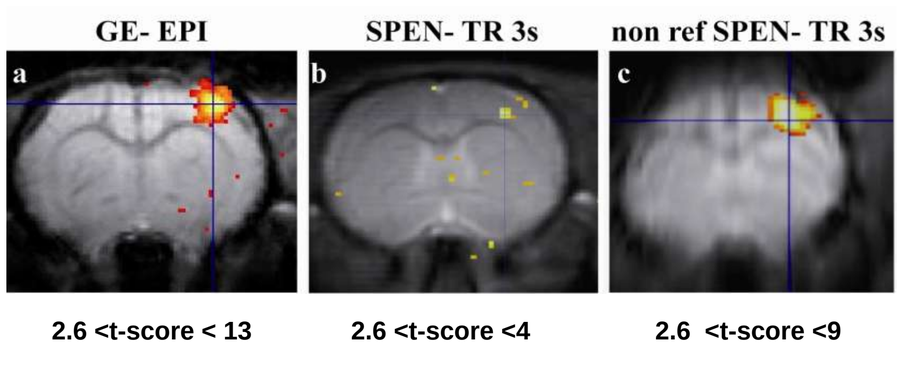

Figure 4: Comparison between GE-EPI, fully refocused and non – refocused SPEN fMRI maps recorded at 17.2 T. (a) GE- EPI; (b) fully refocused SPEN, TR 3s (c) non refocused SPEN;,TR 3s.

DISCUSSION

- SPEN: method of choice for ultra-high magnetic field fMRI due to an enhanced robustness vis-à-vis field inhomogeneities and the chemical shift artifacts.
- TR signal dependence (Fig. 3) strongly suggests that T1-related effects contribute to the fMRI fully refocused SPEN. Further evidence of this T1 contribution: at 7T, as T1 gets shorter, fMRI enhancement decreases.
- Non-refocused SPEN allows strong fMRI signal enhancement –similar to classical T2*-driven BOLD contrast- while preserving good quality of image.
- Strong activation effects observed at very high fields in fully self-refocused mode can be related to in-flow and/or to T2* effects: possible variations of contrast as function of chosen sequence parameters

CONCLUSIONS

- fMRI SPEN: besides the T2*-weighted BOLD contribution in non-refocused sequences, signal contains a strong component caused by apparent T1-related in-flow effects.
- SPEN: very attractive and interesting tool to explore functional activation.

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