Multi-Phase Passband Cine SSFP: an fMRI technique with excellent spatiotemporal resolution at 7 Tesla

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Target audience: Neuroimaging scientists.

Purpose: Passband steady state free precession (SSFP) fMRI employs the flat portion of the SSFP off-resonance response to measure MR signal changes elicited by changes in blood oxygenation following increases in neuronal activity.[1, 2] This technique can overcome geometric distortion and signal dropout while maintaining rapid acquisition and high signal-to-noise ratio (SNR) compared with GE-EPI, and it is less sensitive to physiological noise compared with transition band SSFP.[3] In the study, we present a novel multi-phase SSFP cine fMRI technique that can achieve a spatial resolution of a few mm^3 and a temporal resolution of 50ms at 7 Tesla.

Methods: The study was conducted on a 7T Siemens Magnetom whole-body MR system (Erlangen, Germany) with a 24-channel Nova Medical head coil. Five subjects (2M/3F) participated in Experiment 1. A multi-phase cine SSFP sequence was applied for the event-related (ER) fMRI paradigm (Fig. 1). Each acquisition window with a duration of 16s consisted of 303 time frames. Fifteen k-space lines were acquired per segment, resulting in a temporal resolution of 52.65 ms. A Transistor-Transistor Logic (TTL) pulse at the beginning of data acquisition window was used to trigger the presentation of visual stimulation - 2s' full-screen flashing checkerboard followed by 14 s' resting state. To minimize transient signal oscillations, a train of 20 dummy radiofrequency pulses with ramping flip angles of a Kaiser Bessel window was applied. Afterwards the signal was continuously acquired by a segmented multiphase SSFP readout with phase encoding advancing in a centric order. The magnetization was restored to the positive z-axis by using an $\alpha/2$ pulse finally. [4] A series of images (8 cycles, N=2424) were collected in 8 min 32 s, and imaging parameters were: TR=52.65ms, FOV=19.2x19.2cm^2, 5mm slice thickness, FA=15^0. Each data set was analyzed using SPM8. The physiological noise was regressed out by motion correction, ICA with GIFT and temporal filtering based on FFT. In order to reliably detect the time lag between different events, Experiment 2 was performed on 8 subjects (4M/4F) with a stimulus delay of 0, 100，200 and 400ms respectively. The imaging parameters and data processing methods were the same as Exp. 1 except that the acquisition window was expanded to 18 s.

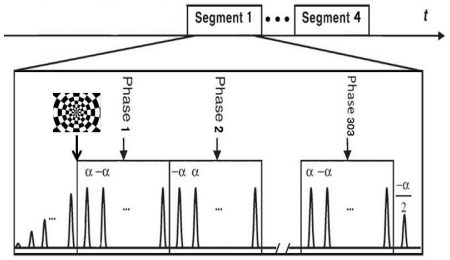

Fig.1 Pulse sequence diagram of the multi-phase SSFP and ER-fMRI paradigm.

Results: Figure 2 displays SPM-t map of a representative subject. The hemodynamic response function (HRF) curve averaged across 5 subjects is derived and shown in Fig.3. The initial dip (arrows) can be reliably detected as well as the post-stimulus undershoot. Fig.4 displays the average HRF curves smoothed and fitted using a double-gamma function for the 0, 100, 200 and 400ms stimulus delay respectively. Temporal delays of the corresponding HRF curves (peak signal change) can be clearly observed.

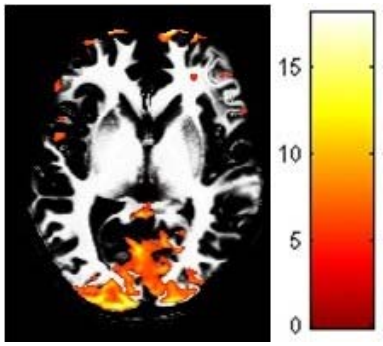

Fig.2 Functional related response onto T1-weighted anatomical images.

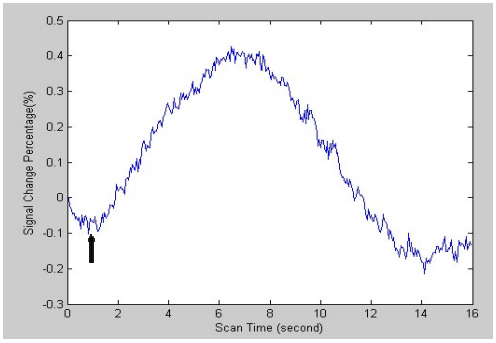

Fig.3 HRF curves acquired with multi-phase SSFP cine fMRI averaged by 5 subjects.

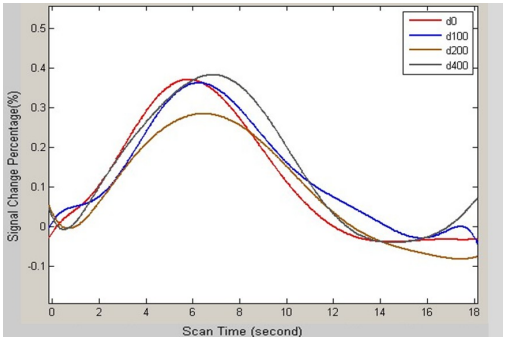

Fig.4 HRF curves of different stimulus delay design.

Discussion: The multi-phase passband SSFP fMRI technique can achieve not only excellent sensitivity and SNR, but also a high temporal resolution of 50 ms. These features are ideal for detecting neural activities with high fidelity and spatiotemporal resolution, such as the initial dip in HRF. The HRF curves in Fig.4 can capture the stimulus delay of 100ms, 200ms and 400ms.

Conclusion: The multi-phase SSFP cine fMRI is a promising technique for functional neuroimaging given its high spatial and temporal resolution at 7 T.

Reference :(1). K L.Miller. FMRI using balanced steady-state free precession (SSFP). Neuroimaging. 2011;62:713-719. (2). J H Lee, et al. Full-brain coverage and high-resolution imaging capabilities of passband b-SSFP fMRI at 3T. MRM. 2008;59:1099-1110. (3). Chen Z, et al. Comparison of SSFP and multiband EPI in functional MRI at 7 Tesla. In: Proceedings of 21th annual meetings of ISMRM. Salt Lake City, Utah, USA.2013; p3323. (4) Yan L, et al. Unenhanced dynamic MR angiography: high spatial and temporal resolution by using True FISP–based spin tagging with alternating radiofrequency. Radiology. 2010;256:270-279.