SSFP fMRI at 0.37 mm3 voxel volume: effects of spatial resolution on SNR and functional sensitivity

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Introduction

SSFP fMRI has been reported to exhibit potential for high resolution fMRI due to absence of geometric distortion [1,2]. Because steady state is maintained through acquisition of all k-lines, SSFP fMRI does not suffer from T2*-related blurring and hence true high resolution imaging can be achieved to increase functional sensitivity via reduction of partial volume effects. Theoretically speaking, spatial resolution in SSFP fMRI is not limited by the length of RF pulse train or matrix size, with major trade-off being the signal to noise ratio (SNR). In this study, we investigate the feasibility of SSFP fMRI at 0.4-millimeter in-plane resolution (voxel volume 0.37 mm^3). Alignment between activated areas and gray matter cortical structures is shown, and the effects of spatial resolution are evaluated.

Materials and Methods

Three volunteers (two males and one female, 24-30 yrs) underwent SSFP fMRI with matrix size of 512x512 (TR/TE/flip angle: 10ms/5ms/6^0, voxel size 0.43x0.43x2mm^3) on a 3.0 Tesla system (Philips Achieva, Best, the Netherlands). High-order shimming was optimized with respect to the occipital lobe. IIR-filtered frequency stabilization was applied to compensate for temporal frequency drift due to systemic heating [3]. A single transverse slice was carefully placed across visual cortex and parallel to calcarine sulcus by referring to a pre-acquired set of 3D T1-weighted images. Three trials with off resonance settings of -8.3Hz, 0Hz, and 8.3Hz, were performed and results combined. In each trial, visual stimulus (5Hz checkerboard, 4 ON, 5 OFF, 8 frames/block, 5.12 sec/frame) was given in 72 dynamic scans. The effects of spatial resolution in the same experimental condition were simulated by down-sampling k-space data from 512x512 to 64, 128, 256, and 384. Data were analyzed by Independent Component Analysis (ICA) [4]. Activation signal level was evaluated by calculating the averaged difference between activated and rest states, with first three time points of each block excluded. Signal to noise ratio (SNR) was also calculated from the first dynamic scan of each image set, by comparing parenchyma signal in occipital lobe.

Results

Figure 1 showed activation maps from 15 sets of SSFP fMRI with off resonance setting of -8.3Hz, 0Hz, and 8.3Hz shown in (a), (b), and (c), respectively. As shown in previous studies, slight change of frequency setting altered SSFP fMRI sensitivity areas and therefore changes of activation pattern [1]. For image sets with same off frequency setting, note that with 64 or 128 matrix (as used in conventional EPI fMRI), activation pattern is rather coarse compared with underlying T1-weighted images. As fMRI resolution increases, activated areas accorded more delicately with gray matter borders of T1-weighted images. In addition, at high resolution, most activated voxels seemed to be located in the microvessels in cortex, appearing as tiny bright spots. Figure 2 plotted the SNR of each trial at different image resolution. As expected, SNR decreased as image matrix size increased. Nevertheless, Fig.3 plotting the activation signal versus matrix size showed, that the functional signal change increased as image resolution went higher in all three fMRI trials, even though overall SNR dropped substantially at highest resolution as shown in Figure 2. At highest resolution, activation signal (14.7-17.1%) was larger than 14% in all trials.

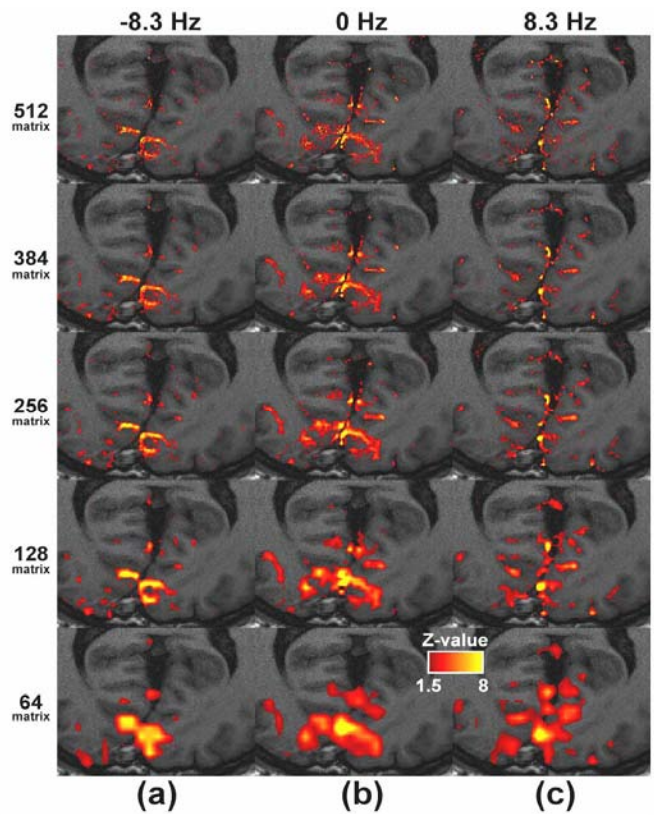

Figure 1. Functional activation maps overlaid on high resolution T1 images. Trials with off resonance settings of -8.3Hz, 0Hz, and 8.3Hz were shown in (a), (b), and (c), respectively. Note the excellent localization of activation area on the microvessels near the gray matter on the high-resolution maps.

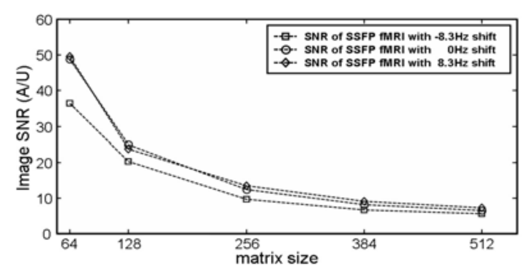

Figure 2. Image SNR versus fMRI matrix size.

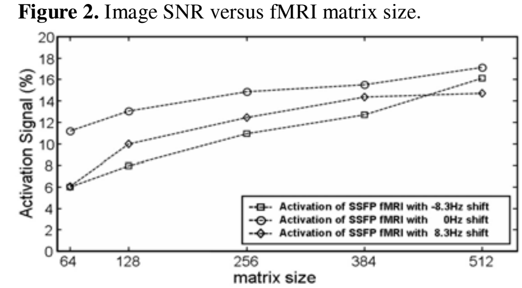

Figure 3. Activation signal level versus fMRI matrix size.

Discussion

Our results demonstrated the feasibility of distortion-free SSFP fMRI at voxel volume of 0.37 mm^3 (in-plane resolution of 0.4 mm), which to the best of our knowledge has not been reported before. A trend of elevation in percentage activation signal was observed with increased fMRI spatial resolution even with substantial SNR drop, which agreed with results of previous studies [1,2,5]. The increased sensitivity at lowered SNR is anticipated to be a result from reduced partial volume effect. In addition to the advantage of improved functional sensitivity with SSFP fMRI, the high spatial resolution achievable in this study allows a precise functional identification and localization of a specific cortex boarder or gray matter nucleus. Although the current temporal resolution of high resolution SSFP fMRI is relatively low compared with single-shot EPI, this could potentially be improved by using parallel imaging techniques. Therefore, we conclude that SSFP fMRI is an effective method for functional brain mapping at high spatial resolution. Additional experiments are required to find out to what extent the reduced voxel size contributes to increased activation signal without decreasing SNR to a level leading to difficulties in detecting activation areas, such that an optimized fMRI spatial resolution considering functional contrast could be found.

Reference 1. Miller KL et al., MRM 2003;50:675. 2. Miller KL et al., MRM 2006;55:161. 3. Wu ML et al., ISMRM 2006:#2815. 4. McKeown MJ et al., HBM 1998;6:160. 5. Lee JH et al., MRM 2006;55:1197.