Considerations on scan parameters in passband SSFP fMRI

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<u>*Introduction*</u> Balanced steady-state free precession (bSSFP) has been recently introduced to measure the hemodynamic responses in human brains [1-3]. Particularly, passband SSFP fMRI generates higher functional contrast in relatively short TRs, providing the potentials for high-resolution fMRI [4-6]. Moreover, it can emphasize the signal from capillaries in the extravascular space and has a potential to better localize the activation area [7,8]. As shown in the previous studies, the functional contrast and the signal to noise ratio in balanced SSFP fMRI are functions of MR parameters [6,8,9]. However, its optimal scan parameters for passband SSFP fMRI have not been investigated systematically. In this study, we suggest a guideline for selecting the scan parameters for passband SSFP fMRI.

<u>*Methods*</u> The Monte Carlo simulation method in [8] was used to estimate the parameter characteristics hard to study experimentally.

All the experiments were performed on a 3.0 T EXCITE MRI with a standard GE head coil. Seven healthy volunteers were recruited and provided informed written consent approved by Stanford University. A circular checkerboard stimulus of 8 Hz contrast-reversing annulus grating flashing was used for the visual stimulation. It started with a 30 second resting period and alternated stimulation and rest states of 30 seconds each for three minutes. Six second idle time preceded the first resting period to ensure the steady state of the signal. The subjects were instructed to stare at the center of the visual stimulus and the visual cortex was observed. The passband SSFP sequence used a 3D stack-of-spirals trajectory (FOV = 24×24×10 cm^3, resolution = 3.75×3.75×5 mm^3, number of interleaves = 4 and BW = ±125 kHz). In order to remove the banding artifacts in the region of interest, linear shimming [10] was targeted at the occipital lobe of the brain. Seven balanced SSFP fMRI experiments were performed with seven different pairs of TRs and flip angles. To measure the TR dependency we tested four different TRs (10.0 ms, 12.5 ms, 18.75 ms, 25.0 ms) while the flip angle was fixed to 25°. The 3D volume data was acquired every 0.8, 1.0, 1.5 and 2.0 seconds for each TR. For flip angle dependency we tested four different flip angles (15°, 25°, 35°, 45°) while TR was 12.5 ms. TE was assumed as the time from the middle of the RF excitation pulse to the middle of the data acquisition, and was set to be a half of TR for all the TRs except TR = 10.0 ms. When TR was 10.0 ms, the readout started right after the refocusing gradient of the slab selective excitation pulse because TR was too short to accommodate the spiral readout gradients in the middle of TR.

<u>*Results & Discussion*</u> First of all, considerations on TR were explored. As seen in figure 1(a), longer TR generally increases the signal change by allowing more dephasing before the signal refocuses by RF excitation pulses. However, in SSFP long TR is generally avoided because it results in more frequent repetition of banding artifacts (figure 1(b)). Therefore, if long TR is used in order to achieve larger signal change, carefully tuned targeted shimming [10] is required. TR also changes the vessel size selectivity as in figure 1(c). Even though the simulation result provides only extravascular space signal change, selecting TR between 8 ms and 20 ms will generate significant signal change in capillary and relatively small signal change in large veins and it will better localize the activation area.

The signal change can be also increased using larger RF flip angle as seen in figure 2(a). However, the flat part of the SSFP off-resonance profile shrinks as the flip angle increases past 25~35 degrees (gray matter, 3 T), and there is a potential to exaggerate the signal change near the off-resonance bandings (see arrows in figure 2(b) and signal change near ±1/2TR in figure 2(c)).

Higher B0 field increases the signal change. However, In addition, it is interesting to note that the B0 field scarcely changes the specificity in vessel size as shown in figure 3(a). TE also changes the functional contrast in the passband SSFP fMRI. As seen in figure 3(b), the signal change with respect to TE shows a u-shaped curve with the larger values for longer TEs. When TE~TR/2, the signal is refocused by the so-called spin-echo effects [11] and this effect contribute to the reduced signal change. On top of the bSSFP refocusing effect, the signal change increases gradually with TE due to the T_2* BOLD effect. The contribution of T_2* contrast seems more prominent in longer TRs.

<u>*Conclusion*</u> The scan parameters were investigated to find their optimal values in passband SSFP fMRI. TR of 10 ~ 20 ms generates detectable function contrast in the scan time shorter than 3 minutes and shows the spatial specificity. Flip angle of 25 ~ 35 degrees shows relatively flat off-resonance profile of signal change (gray matter, 3T) with reasonably high functional contrast.

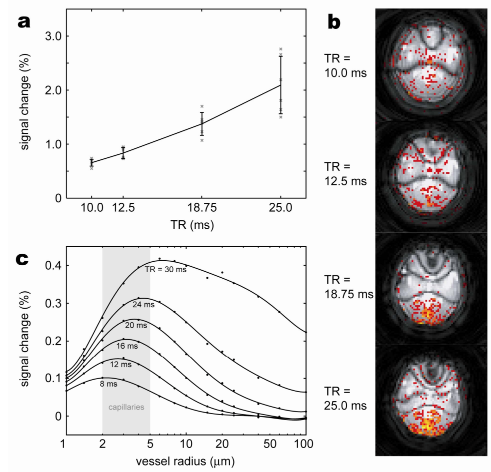

Figure 1. *(a) Relative signal change increase almost linearly as TR becomes longer. (b) Large TR picks up more activation regions; however, banding artifacts appear more frequently. (c) Simulation result. TR between 10 ~ 20 ms picks up the signal change selectively from capillary area..*

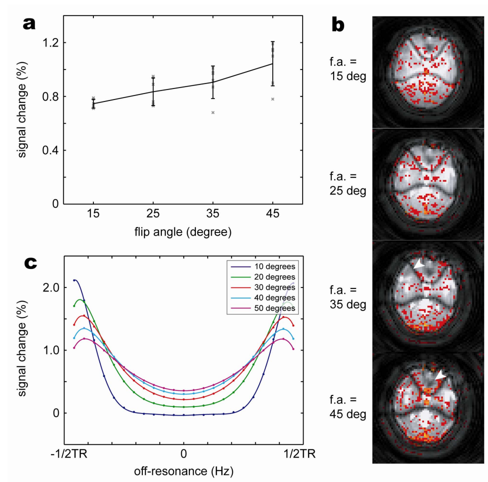

Figure 2. *(a) Relative signal change increase as flip angle becomes longer. (b) The larger flip angle picks up the more activation regions; however, banding artifacts are wider and false activations (arrowheads) are generated near the banding artifacts. (c) The simulation result clearly shows that the large flip angle generates the less flat off-resonance profile of relative signal change.*

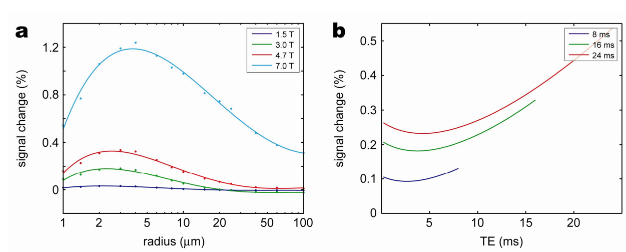

Figure 3. *(a) Relative signal change in several main field strength. Interestingly, the specificity in vessel size hardly changes. (b) Relative signal change with respect to TE.*

<u>*References*</u>
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