RECOVERING TSNR AND BOLD SENSITIVITY BY COMBINING HYPERBOLIC SECANT RF EXCITATION PULSES AND COMPENSATORY GRADIENTS

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Target audience: This work will be of interest to those using task-based and resting-state FMRI, acquired with gradient-echo echo-planar imaging, to investigate function in brain regions currently affected by signal dropout.

Purpose: FMRI data acquired using gradient-echo echo-planar imaging (GE-EPI) suffers from signal-dropout in the orbitofrontal cortex (OFC) and temporal lobes (TL) [1] caused by susceptibility gradients in the slice-selection, Gx,s, phase-encoding, Gy,s, and readout, Gz,s, directions. For the first time we combine the use of full-passage scaled-down Hyperbolic Secant (HS) excitation pulses [2] and gradient compensation in the readout direction [3] to recover BOLD signal in regions with signal dropout caused by Gx,s and Gz,s. We demonstrate improvements in temporal signal-to-noise ratio (TSNR) and BOLD sensitivity in the OFC and TL of six healthy male volunteers compared to conventional GE-EPI.

Methods: The parameters of a HS excitation pulse with amplitude $A(t)=A_0 \text{sech}(\beta t)$ and phase $\phi(t)=\mu \ln[\text{sech}(\beta t)]$ were optimized by Bloch simulation* in MATLAB to give the most uniform signal response for $G_{x,s} \pm 300 \mu T m^{-1}$ (pulse duration $T=5$ms, $\beta=3040$Hz and $\mu=4.25$). Susceptibility gradients in the read-out direction shift the position of the echo in k-space; dropout occurs when the shift is greater than $0.5/\Delta x$ i.e. echo occurs outside the acquisition window ($\Delta x$ is the voxel size in the readout direction). Signal is also reduced at smaller echo shifts due to k-space filtering during image reconstruction. By combining, by sum-of-squares (SSQ), two volumes acquired with negative and positive compensatory gradients, that shift the echo by $\pm 0.3/\Delta x$, signal can be recovered. The TSNR of conventional GE-EPI sequence (with an SLR excitation pulse) and the 2-step x-gradient compensation combined with optimized HS pulse was measured using data from two 450 volume EPI scans (conventional GE-EPI and the 2-step method). It was calculated voxel-wise as the ratio of the temporal mean to the temporal standard deviation, motion correction and high pass filtering (cut-off 0.01Hz) to remove signal drifts. BOLD sensitivity was assessed using a breath-hold experiment [4,5], in which subjects were visually cued to perform 48s blocks of paced breathing interleaved with 16s blocks of breath-holding. The differences between the two acquisition methods was assessed using the difference in raw z-statistic maps; produced by fitting a block design (with 16s blocks of breath-holding). The differences between the two methods were assessed using a breath-hold experiment. Due to the reduction in temporal resolution (because of the requirement to perform 2-steps) this technique is most appropriate for block designs (confirmed using a simple motor task – data not shown); event related experiments are unlikely to be possible and the effect of SSQ on resting-state analysis is still to be determined. This technique could be extended by the addition of gradient compensation in the phase-encoding direction to further reduce signal dropout, however this would result in a further reduction in temporal resolution.

* Bloch simulation code written by Dr B. Hargreaves (www-mrsrl.stanford.edu/~brian/blochsim)