# 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, $G_{z,s}$, phase-encoding, $G_{y,s}$, and readout, $G_{x,s}$ ,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 $G_{z,s}$ and $G_{x,s}$. 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 $A(t)=A_0\mathrm{sech}(\beta t)$ and phase $\phi(t)=\mu.\ln[\mathrm{sech}(\beta t)]$ were optimized by Bloch simulation* in MATLAB to give the most uniform signal response for $G_{z,s}$ $\pm300\mu\mathrm{Tm}^{-1}$ (pulse duration T=5ms, β=3040Hz and μ=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/Δx i.e. echo occurs outside the acquisition window (Δx 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 ±0.3/Δx, 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 10s delay to account for HRF lag), convolved with a gaussian kernel (σ=7.48) in FSL FEAT (after motion correction, high pass filtering (cut-off 0.01Hz) and spatial smoothing (5mm kernel)). All data were acquired at 3T using a GE MR750 system (General Electric, Waukshua, WI, USA); thirty-six AC-PC slices were acquired top-down sequentially with a slice thickness of 3mm and 0.3mm gaps. The field-of-view was 21.2cm with a 64×64 matrix and an acceleration (ASSET) factor of two. The flip angle=73°, TR=2s and TE=30ms. The body coil was used for RF transmission and an 8-channel head coil for signal reception.

**Results:** A representative slice through the orbitofrontal cortex of one of the six subjects is shown for data acquired with conventional GE-EPI, Fig.1, and with the new 2-step method in Fig. 2. Fig.3 shows the percentage difference in TSNR between the two methods. The differences in raw z-statistic images from breath-hold experiments acquired using the two techniques is shown in Fig. 4.

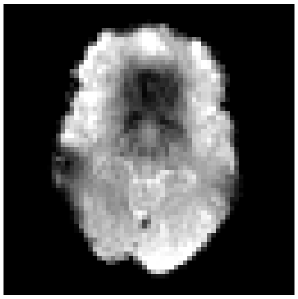
Figure 1. GE-EPI

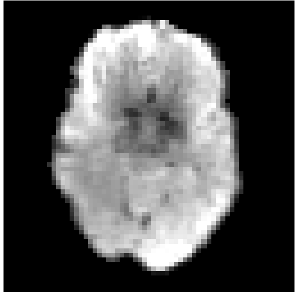
Figure 2. Two-step x-gradient compensation combined with optimized HS pulse

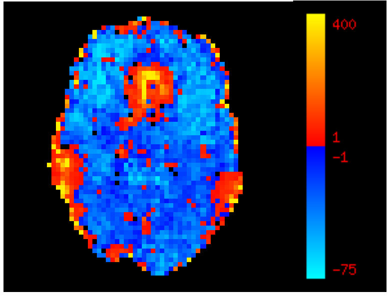

Figure 3. Percentage difference in TSNR

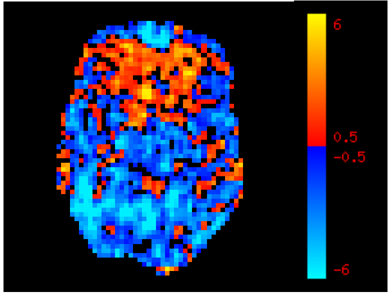

Figure 4. Difference in z-statistic from breath-hold experiments

**Discussion and Conclusions:** We have shown that the 2-step x-gradient compensation combined with optimized HS pulse can be used to recover signal in large numbers of voxels in the OFC and TL, albeit with up to 75% loss in TSNR in regions unaffected by susceptibility gradients. Importantly, for FMRI applications, this signal increase in the OFC and TL results in BOLD signal recovery as demonstrated 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.

**References:** [1] J. G. Ojemann et al, *NeuroImage*, **1997**, 6, 3, 156-167
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* Bloch simulation code written by Dr B. Hargreaves (www-mrsrl.stanford.edu/~brian/blochsim)