The effect of flip angle on BOLD fMRI sensitivity

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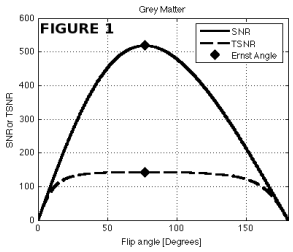
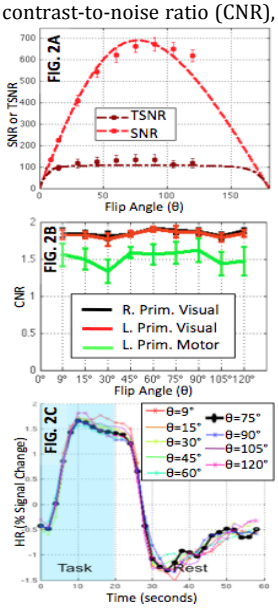


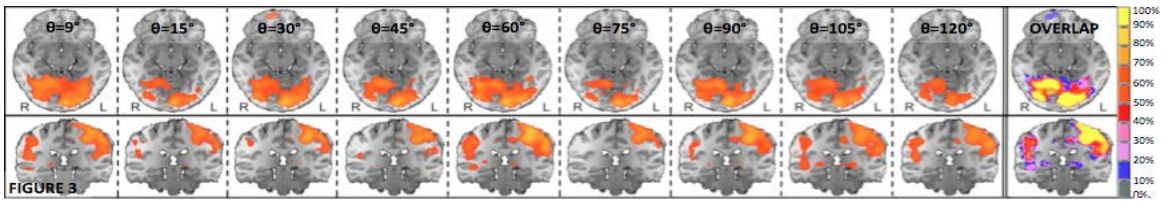
INTRODUCTION: It is known [1, 2] that noise variance in an imaging voxel (σ_{fmri}) for gradient recalled-echo (GRE) acquisitions can be modeled as the sum of thermal noise (σ_o) and physiological noise (σ_p). Thermal noise (σ_o) arises from the subject and scanner electronics, and is independent of MR-signal strength [1, 3]. Physiological noise (σ_p) is directly proportional to MR-signal strength ($\sigma_p=\lambda\cdot S$), and creates the following non-linear relationship between SNR & TSNR: $TSNR=SNR/(1+(\lambda\times SNR)^2)^{1/2}$. One direct result of this relationship is that when $\sigma_p>>\sigma_o$, SNR and TSNR show different behaviors as a function of flip angle (θ) (Fig. 1). In particular, while SNR decreases abruptly for θ other than the Ernst angle, TSNR stays fairly constant and close to its maximum for a wide range of θs. We hypothesize that this behavior can be exploited to perform fMRI at θ well below the Ernst angle without any detrimental effect on our ability to detect BOLD neuronal activation. To test this hypothesis we conducted a block-design experiment with a combined visual-motor task. Using this data, we examined flip angle effects on the time-course of the hemodynamic response (HR) and regression coefficients (β) associated with the task, on contrast-to-noise ratio (CNR), and on statistical maps of activation. Results suggest that our hypothesis is correct.



METHODS: 8 subjects (4M+4F). ***TASK:*** Functional runs consisted on 5 repetitions of the following sequence of blocks: Task [20s | Flickering checkerboard at 7.5Hz + Sequential Button Pressing at 2.5Hz]; and Rest [40s | Focus on fixation crosshair]. ***DATA ACQUISITION:*** 3T Signa HDx Scanner. Functional Data (GRE-EPI, TR/TE=2.0s/30ms, 32 axial slices, 3.75x3.75x4mm). Anatomical Data (T1-weighted MPRAGE 1x1x1.2mm). Functional runs at θ=15°,30°,45°,60°,75°,90° & 105° were collected for all subjects. Data for θ=9° and θ=120° were collected only in 7 subjects. An additional GRE-EPI run with effective flip angle of zero (the MR scanner's RF amplifier disabled) and all other parameters matching those of the functional runs was collected to compute σ_o. ***DATA ANALYSIS:*** (a) intra-run motion correction; (b) spatial registration to the 1st volume of the θ=90° run; (c) discard initial 5 volumes; (d) signal detrending & normalization; and (e) general linear regression with AFNI 3dDeconvolve. For each θ, we computed SNR, TSNR, CNR, HR, and activation overlap maps [4]. SNR & TSNR were computed for WM, GM & CSF. CNR & HR were estimated using significantly active voxels (pFDR<0.05) in three distinct ROIs (L & R Visual Cortex, Left Motor Cortex). To quantify activation overlap across angles, we computed the Ratio of Volume Overlap ($R_{overlap}$) for each angle-pair of each subject. Mean $R_{overlap}$ across subjects was calculated to summarize.

RESULTS: Fig 2.A shows SNR & TSNR in GM. Similar results were found for WM & CSF. SNR reaches a maximum for the Ernst angle and rapidly decreases as we move away from that angle. In contrast, TSNR stays fairly constant for a wide range of angles. Fig 2.B shows CNR for L&R Visual and for the Left Motor ROI. CNR showed no significant changes as a function of θ ($F=1.09$; $p=0.37$). Fig. 2.C shows estimated HR for the left Visual ROI. No systematic differences in HR were observed across angles, neither during the active or rest periods. Similar results were found on the other 2 ROIs. Fig. 3 shows activation maps ($p_{FDR}<0.05$) in visual and motor cortex for all θ on a representative subject. Activation overlap across all θ is depicted in the right most column (yellow indicates voxels consistently active at all θs). $R_{overlap}=0.65\pm0.06$ across the whole brain. $R_{overlap}=0.91\pm0.04$ if computed for the Visual ROIs only.

DISCUSSION & CONCLUSSIONS: Our results confirm that the use of angles as low as θ=9° does not affect recorded HRs, nor introduce significant changes in CNR, and ultimately has no negative effect on the detection of BOLD-related activations. HR estimations associated with task epochs were reliably detected in all subjects for both bilateral visual and left primary motor cortex. This result suggests that the signal percent change that accompanies task-related neuronal activation has negligible dependence on θ. A similar result was obtained in terms of CNR. Detected patterns of activation in visual and motor cortex were consistent across angles for all subjects. Although some level of variability can be observed in the overlap maps, the amount of variability does not exceed previously reported test-retest within-subject variability for similar visual and motor tasks. Evaluation of plausible flip angle effects on the estimation of regression coefficients (β) (not shown in this abstract) at single-subject statistical analysis also rendered not significant. This result suggests that second level statistical analysis (group analysis), which uses as input β coefficients from individual subjects, should not be negatively affected by the use of low flip angles. We believe these results have important implications for experimental fMRI, as the use of small flip angles provides important additional benefits such as better tissue contrast, less inflow effects, less through-plane motion artifacts, lower physiological noise levels, shorter scanning times, and reduced levels of radio-frequency (RF) energy deposition.



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