

#3624

THE EFFECT OF FLIP ANGLE ON BOLD FMRI SENSITIVITY

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WHY SHOULD WE CONSIDER LOW FLIP ANGLES (θ)?

- Reduction of RF Power → Lower Heat Deposition
- Limitation of Apparent T_1 -related Inflow Effects
- Reduction of In-Plane Motion Artifacts
- Lower Levels of Physiological Noise
- Higher Tissue Contrast → Improved Alignment

IF LOW θ ARE SO GOOD, WHY PEOPLE COMMONLY CHOOSE THE ERNST ANGLE (θ_{ERNST})?

- Maximizes Signal Level
- Maximizes Image Signal-to-Noise Ratio (SNR)

But, what about Temporal Signal-to-Noise Ratio (TSNR) or Task-based BOLD Contrast? Are we necessarily also maximizing those?

SIGNAL IN GRE-EPI DATA

**STEADY STATE
SIGNAL (S)**

$$S = M_o \cdot e^{-TE/T_2^*} \cdot \frac{(1 - e^{-TR/T_1}) \cdot \sin(\theta)}{1 - e^{-TR/T_1} \cdot \cos(\theta)}$$

NOISE IN GRE-EPI DATA

RAW NOISE [σ_o]

Thermal Noise from Scanner/Subject
Drift, Gradient Imperfections, etc.

$$\sigma_o \not\propto S$$

PHYSIOLOGICAL NOISE [σ_p]

Fluctuations in Basal Metabolism
Fluctuations from Cardiac/Respiratory Functions

$$\sigma_p = \lambda \cdot S$$

TOTAL NOISE [σ_{TOTAL}]

$$\sigma_{TOTAL} = \sqrt{\sigma_o^2 + \sigma_p^2}$$

$$\sigma_{TOTAL} \propto S$$

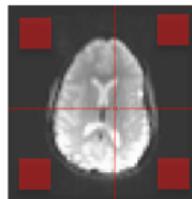
Krüger et al. (2001)

MRI DATA QUALITY METRICS AND THEIR RELATIONSHIP

$$\text{DATA QUALITY} = \frac{\text{SIGNAL LEVEL}}{\text{NOISE LEVEL}}$$

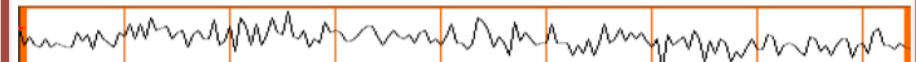
IF NOISE LEVEL = σ_o

$$SNR = S/\sigma_o$$



NOISE = spatial standard deviation (SD) of intensity values in ROI outside the brain

IF NOISE LEVEL = σ_{TOTAL}



$$TSNR = S / \sqrt{\sigma_o^2 + \sigma_p^2}$$

NOISE = voxel-wise temporal SD of intensity across steady-state volumes.

SNR & TSNR SHOW A NON-LINEAR RELATIONSHIP

$$TSNR = S / \sqrt{\sigma_o^2 + \sigma_p^2} \xrightarrow[\sigma_o/\sigma_o]{\sigma_p/\sigma_o} TSNR = SNR / \sqrt{1 + (\sigma_p/\sigma_o)^2}$$

IF THERMAL NOISE DOMINATES

$$\sigma_p/\sigma_o \ll 1$$

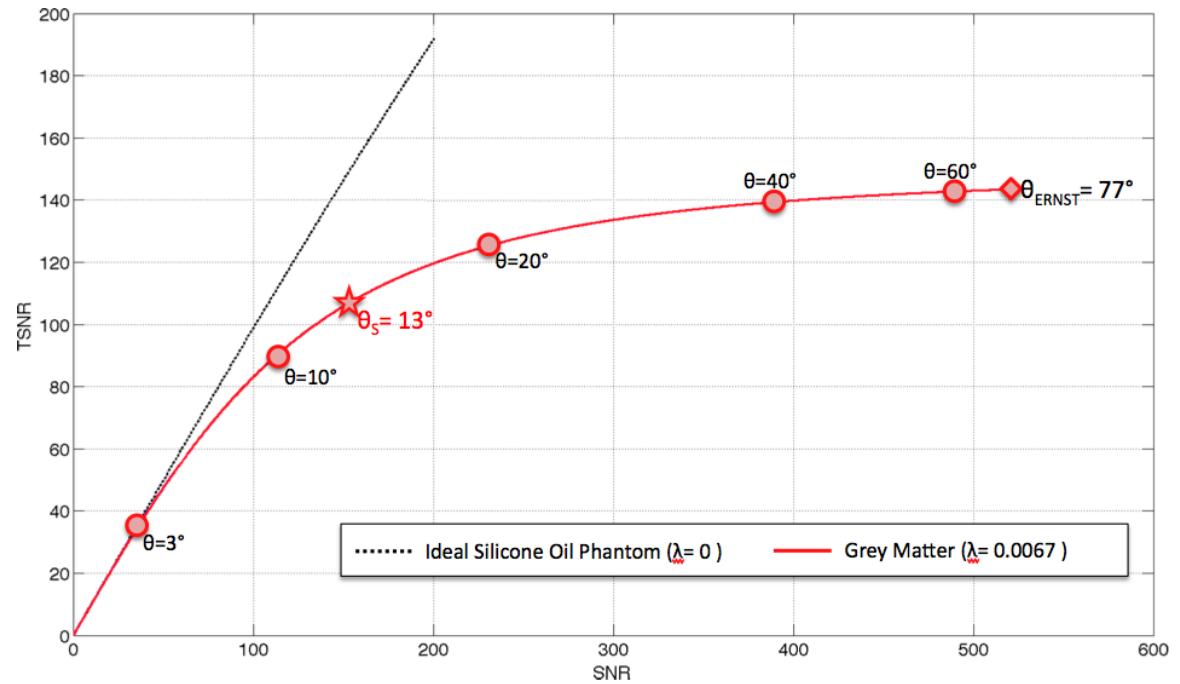
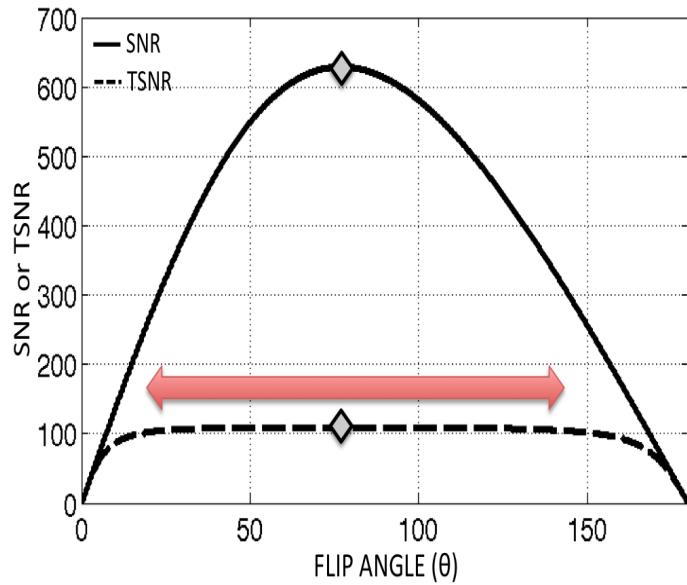
$TSNR \approx SNR$

IF PHYSIOLOGICAL NOISE DOMINATES

$$\sigma_p/\sigma_o \gg 1$$

$TSNR \neq SNR$

SNR & TSNR vs. θ WHEN PHYSIOLOGICAL NOISE DOMINATES



When Physiological Noise Dominates, Flip Angles well below the Ernst Angle produce minimal loss in TSNR

EXPERIMENTAL MOTIVATION & GOALS

1

TEST THEORETICAL PREDICTIONS ON HOW SNR AND TSNR CHANGE WITH FLIP ANGLE

ACQUIRE DATA AT SEVERAL ANGLES

COMPUTE SNR & TSNR

EXPECTED OUTCOME

REPRODUCE THEORETICAL SNR/TSNR CURVES WITH REAL HUMAN DATA

2

TEST IF BOLD FMRI AT LOW FLIP ANGLES PRODUCES RESULTS COMPARABLE TO BOLD FMRI AT ERNST ANGLE WHEN PHYSIOLOGICAL NOISE DOMINATES

HEMODYNAMIC RESPONSE

REGRESSION COEFFICIENTS (β)

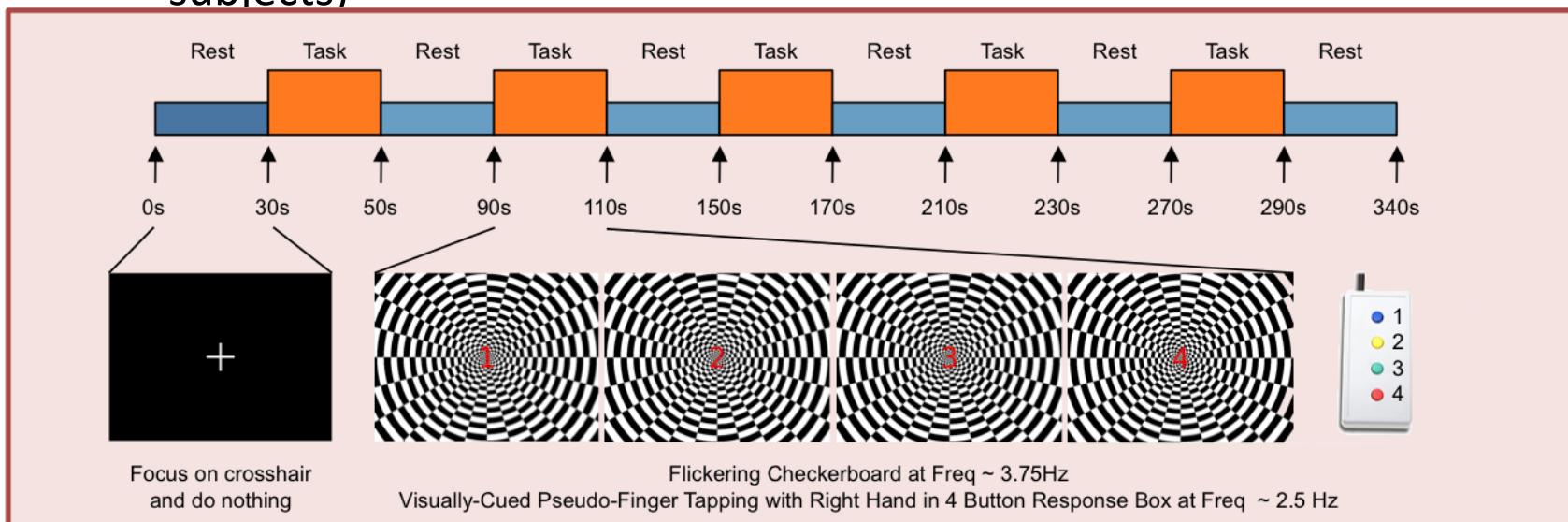
ACTIVATION MAPS

EXPECTED OUTCOME

FLIP ANGLE HAS NO SYSTEMATIC EFFECT ON ANY OF THESE METRICS

METHODS: Data Acquisition

- Eight Subject (4 Males + 4 Females)
- Scanner: 3T Signa HDx | Coil: 16-Channel Nova Medical
- Data Collection:
 - Anatomical Scan: MPRAGE
 - Functional Scans: GRE-EPI
 - TE/TR=30/2000ms; FOV=24cm; 32 Slices; In-plane: 64x64; Thickness=4.0mm
 - $\theta = 9^\circ, 15^\circ, 30^\circ, 45^\circ, 60^\circ, 75^\circ, 90^\circ, 105^\circ, 120^\circ$ (9° & 120° only in 7 subjects)



METHODS: Data Processing

DATA PRE-PROCESSING

- Intra-run Motion Correction
- Spatial Co-registration
- Discard Initial 5 Volumes
- Data Detrending
- Spatial Smoothing (FWHM = 6mm)
- Intensity Scaling (divide by the mean)

STATISTICAL ANALYSIS

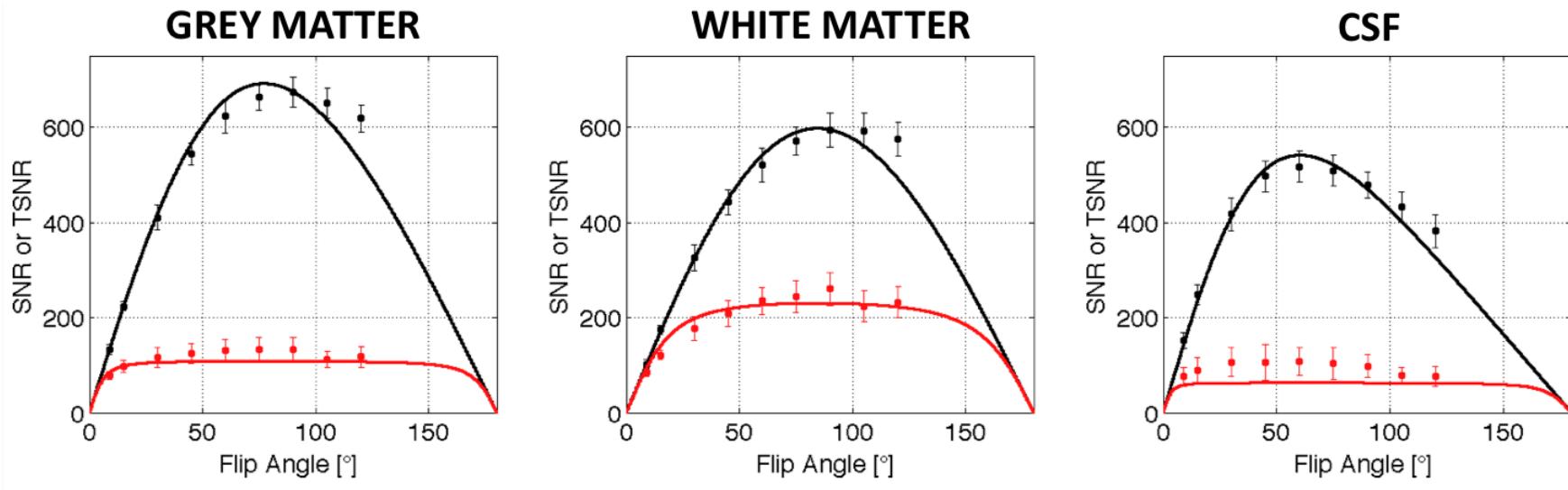
- AFNI 3dREML
- Contrast: Task vs. Rest
- Threshold: $p_{\text{FDR}} < 0.05$

ROI ANALYSIS

- Tissue ROIs (Method by Bodurka et al. 2007):
 - Grey Matter, White Matter, CSF.
- Task Related ROIs (From AFNI Atlases):
 - Right & Left Visual Cortex, Left Primary Motor Cortex

RESULTS: SNR & TSNR vs. FLIP ANGLE

(1) TEST THEORETICAL PREDICTIONS ON HOW SNR AND TSNR CHANGE WITH FLIP ANGLE



● Experimental SNR

● Experimental TSNR

— Theoretical SNR

— Theoretical TSNR

$$\lambda$$

$$.0092 \pm .0023$$

$$\lambda$$

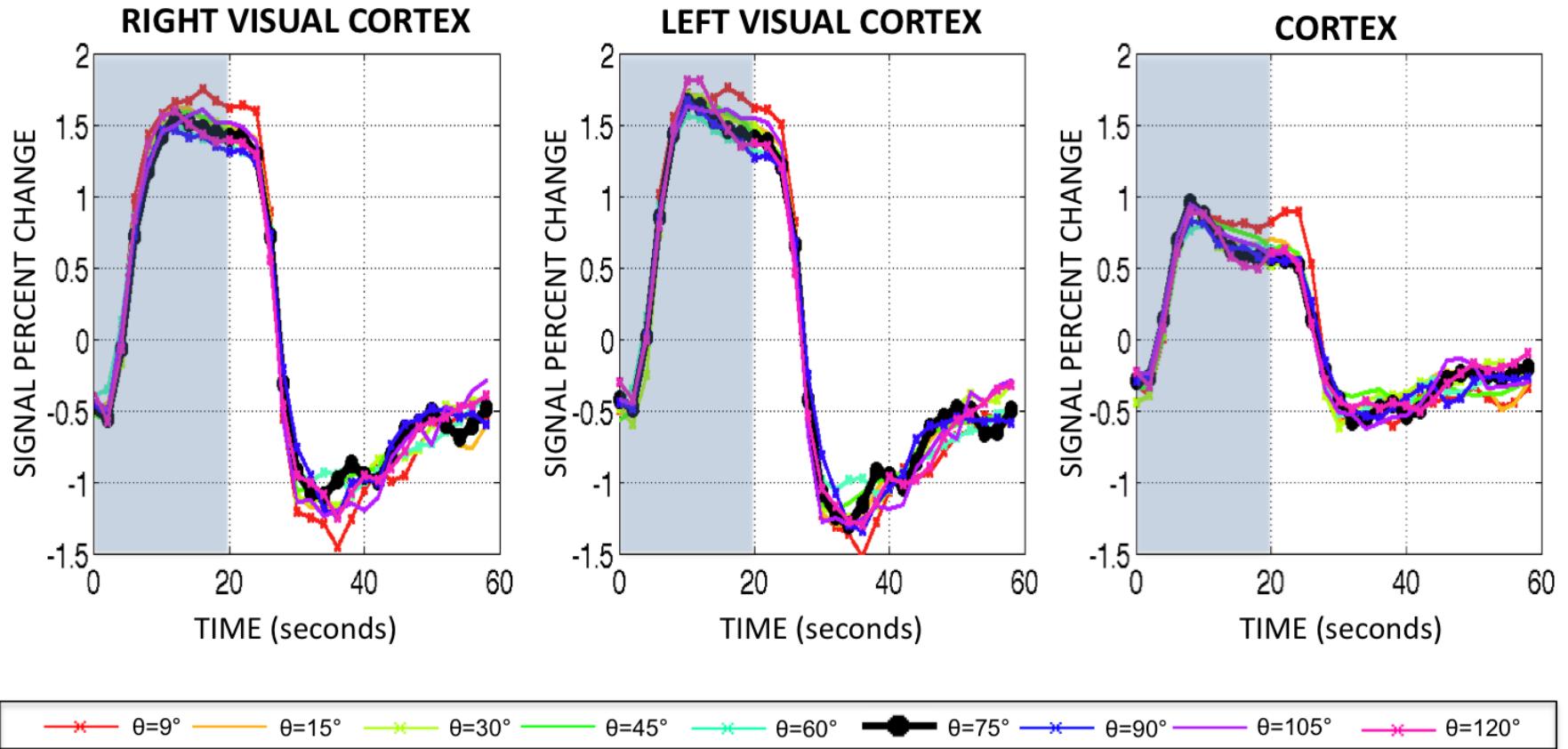
$$.0040 \pm .0011$$

$$\lambda$$

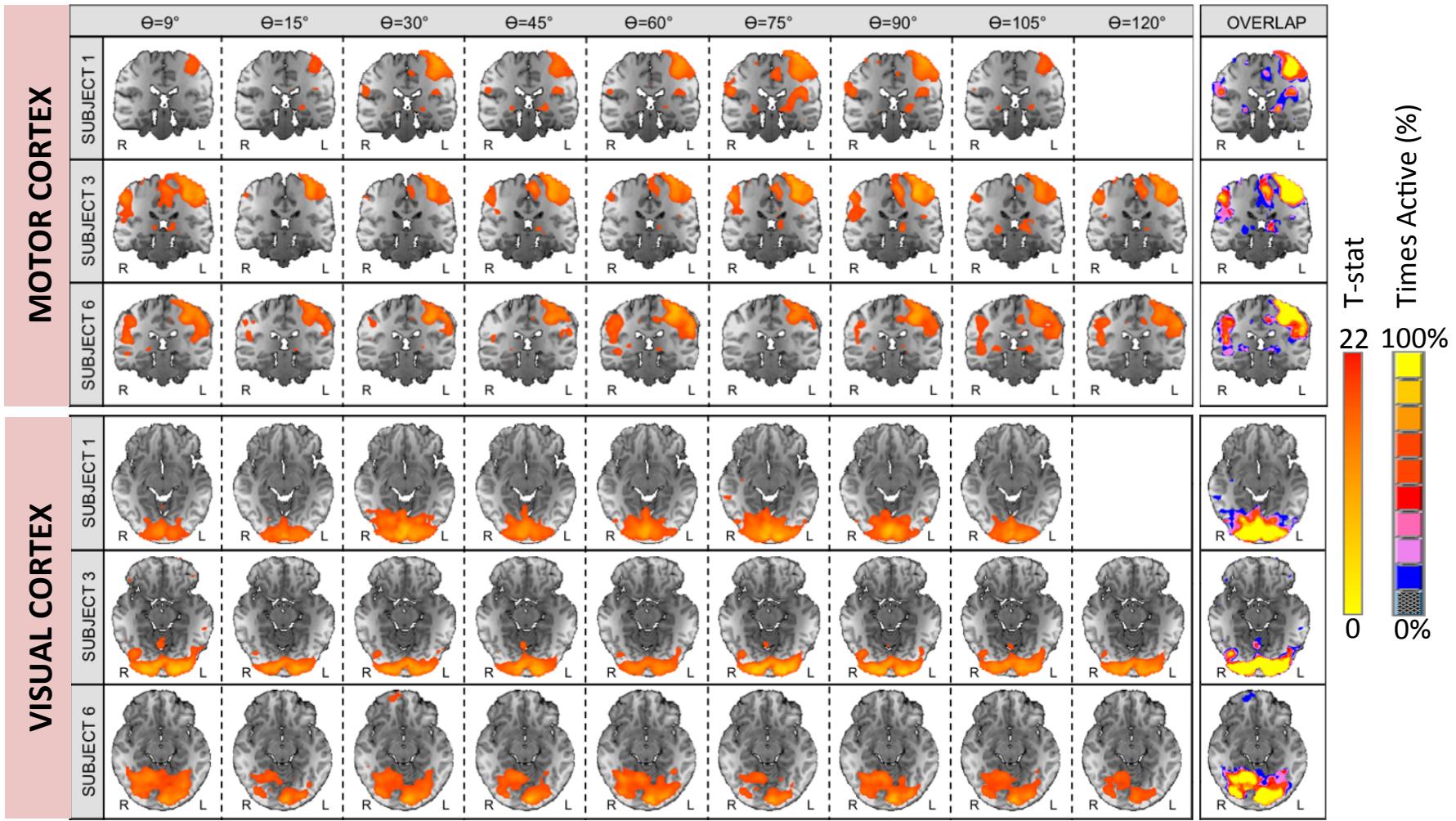
$$.0158 \pm .0072$$

RESULTS: ESTIMATED HEMODYNAMIC RESPONSES

(2) TEST IF BOLD FMRI AT LOW FLIP ANGLES PRODUCES RESULTS COMPARABLE TO BOLD FMRI AT ERNST ANGLE



RESULTS: STATISTICAL ACTIVATION MAPS



REPRODUCIBILITY ACROSS ANGLES

	VISUAL ROI	MOTOR ROI	WHOLE BRAIN
R_{overlap}	0.91 ± 0.04	0.76 ± 0.09	0.65 ± 0.06

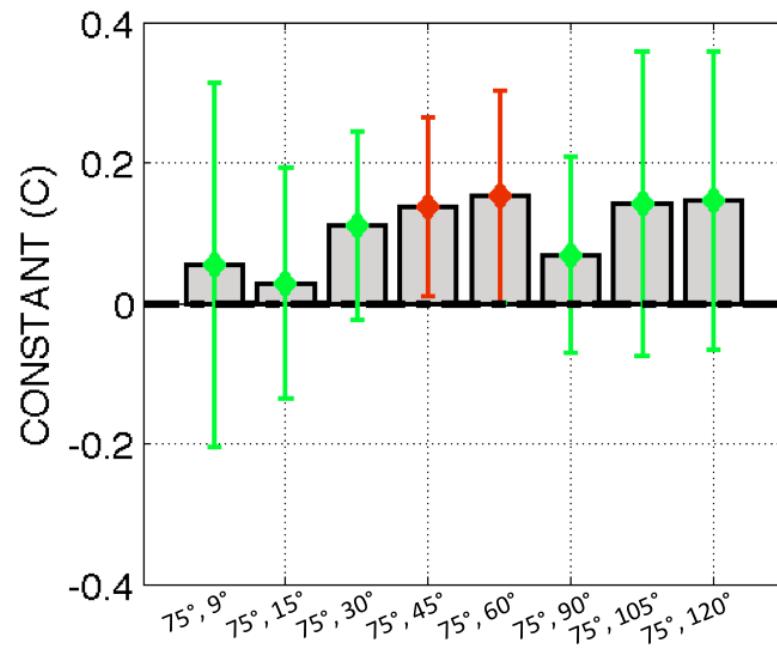
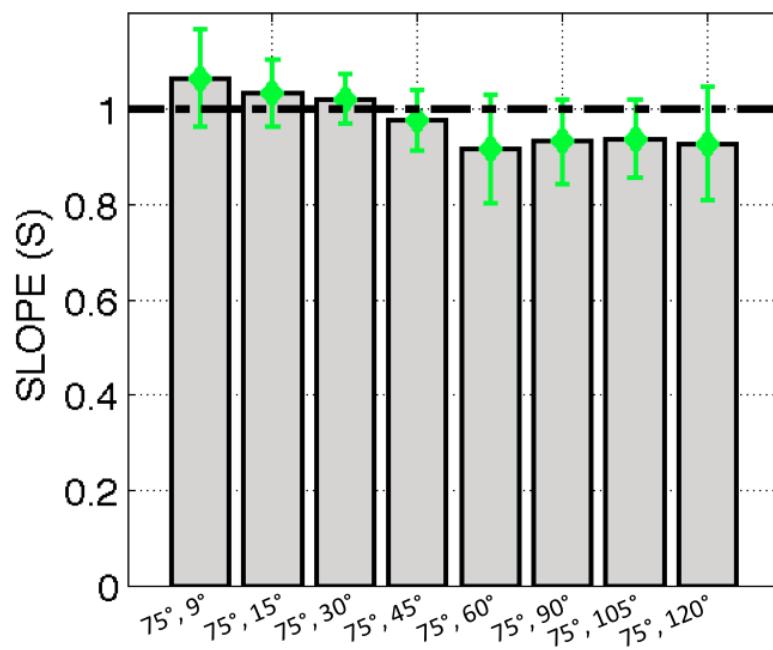
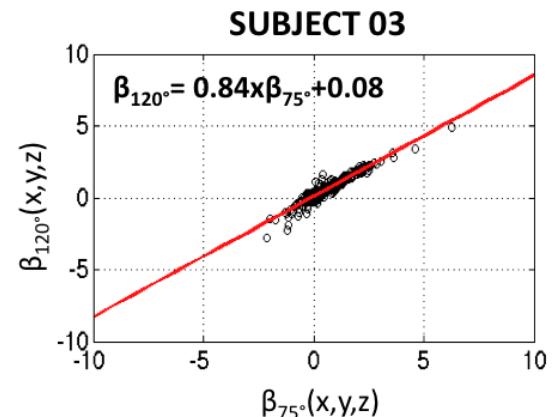
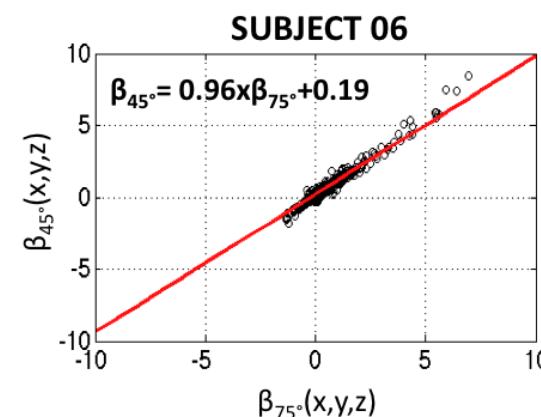
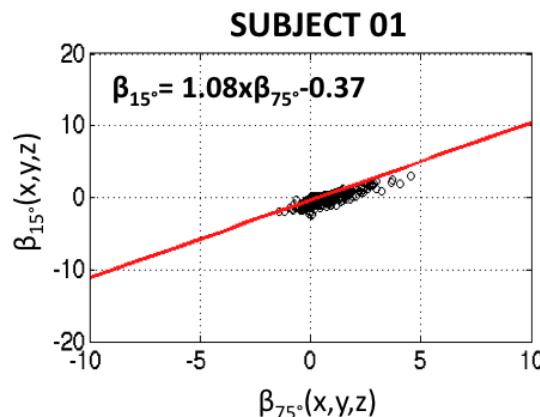
PREV. REPORTED INTRA-SESSION TEST-RETEST

	FLASHING CHECKER	FINGER TAPPING
	$0.56 - 0.66^*$	$0.41 - 0.50^{**}$

*Miki et al. (2001); **Gountouna et al. (2010), Tegeler et al. (1999)

RESULTS: REGRESSION COEFFICIENTS (β)

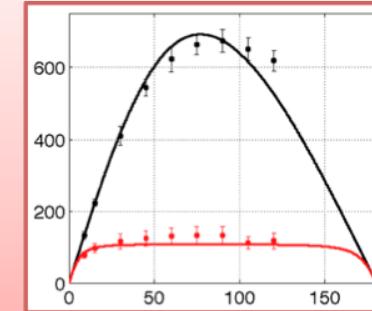
(2) TEST IF BOLD FMRI AT LOW FLIP ANGLES PRODUCES RESULTS COMPARABLE TO BOLD FMRI AT ERNST ANGLE



CONCLUSIONS

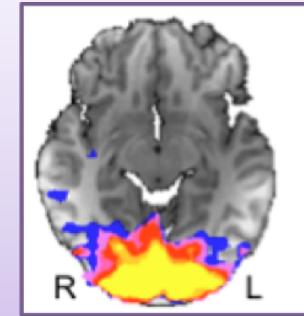
1

THEORETICAL PREDICTIONS ON HOW SNR AND TSNR CHANGE WITH FLIP ANGLE CONFIRMED EXPERIMENTALLY



2

BOLD FMRI AT LOW FLIP ANGLES PRODUCES RESULTS COMPARABLE TO BOLD FMRI AT ERNST ANGLE



WHAT ANGLE DO YOU SUGGEST TO USE?

SHOULD IT BE 10°? 30°?

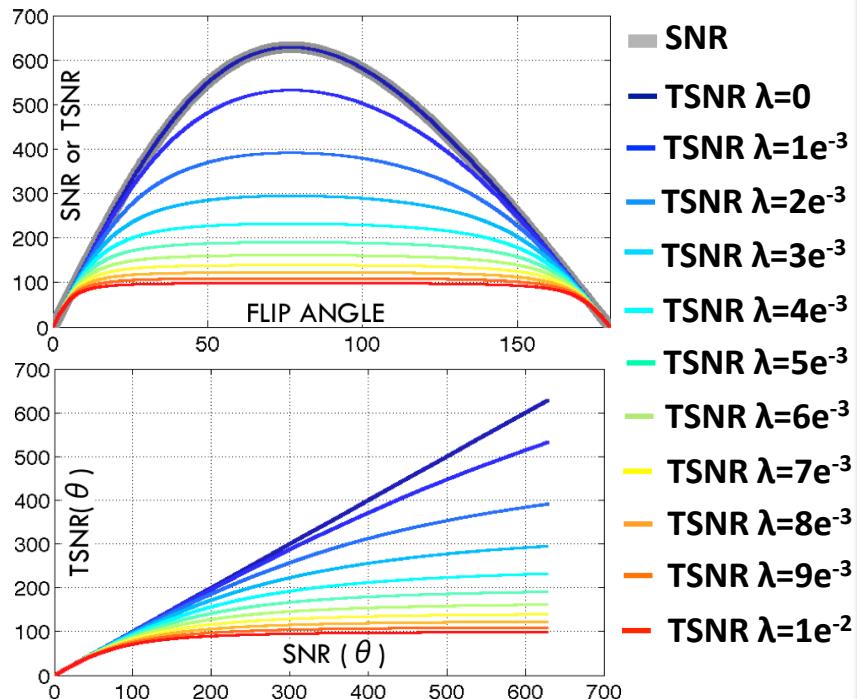
WHAT EXPERIMENTAL FACTORS AFFECT THIS SUGGESTED ANGLE?

SUGGESTED FLIP ANGLE (I)

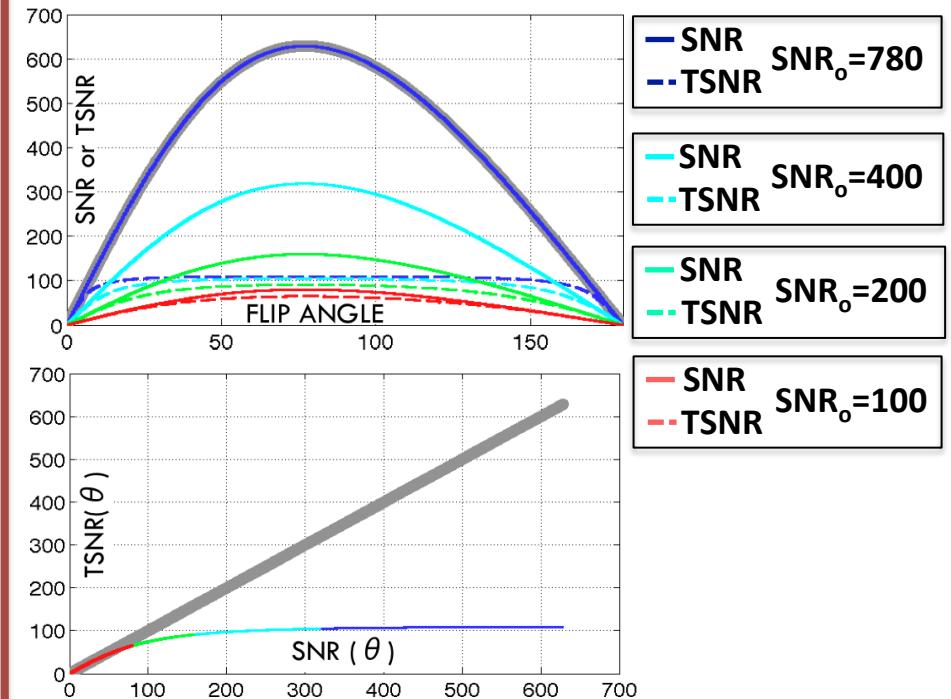
IMAGING AT ANGLES WELL BELOW THE ERNST ANGLE IS POSSIBLE ONLY WHEN PHYSIOLOGICAL NOISE IS THE DOMINANT NOISE SOURCE

TWO EXPERIMENTAL FACTORS DEFINE WHETHER OR NOT WE ARE DOMINATED BY PHYSIOLOGICAL NOISE

PHYSIOLOGICAL NOISE LEVEL (λ)

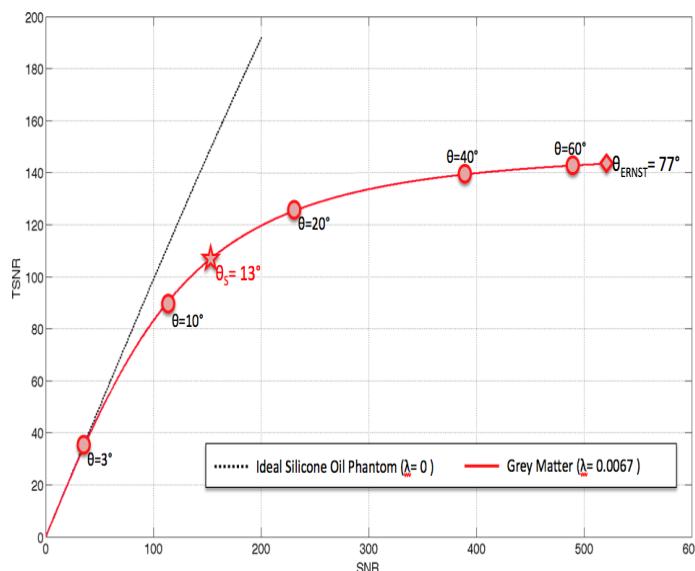


AVAILABLE IMAGE SNR



SUGGESTED FLIP ANGLE (II)

SUGGESTED FLIP ANGLE = FLIP ANGLE FOR WHICH NO NOISE SOURCE DOMINATES $\rightarrow \sigma_p / \sigma_o = 1 \rightarrow$ IF ($TR >> T_1$) $\theta_s = \sin^{-1}(1/\lambda \cdot SNR_o)$



TR	θ_{ERNST}	RESOLUTION [mm]	$\theta_{SUGGESTED}$ BIRDCAGE	$\theta_{SUGGESTED}$ 8CH ARRAY	$\theta_{SUGGESTED}$ 16CH ARRAY
1s	62°	3.8x3.8x4	$\theta_{ERNST} \approx 62^\circ$	>25°	>10°
		1.8x1.8x2	$\theta_{ERNST} \approx 62^\circ$	$\theta_{ERNST} \approx 62^\circ$	$\theta_{ERNST} \approx 62^\circ$
2s	77°	3.8x3.8x4	$\theta_{ERNST} \approx 77^\circ$	>25°	>10°
		1.8x1.8x2	$\theta_{ERNST} \approx 77^\circ$	$\theta_{ERNST} \approx 77^\circ$	>65°
3s	83°	3.8x3.8x4	$\theta_{ERNST} \approx 83^\circ$	>25°	>10°
		1.8x1.8x2	$\theta_{ERNST} \approx 83^\circ$	$\theta_{ERNST} \approx 83^\circ$	>65°

IF INTERESTED IN MORE DETAILS, PLEASE CHECK OUR PAPER:

Physiological noise effects on the flip angle selection in BOLD fMRI

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