Impacts of multiband acceleration factors on sensitivity and specificity

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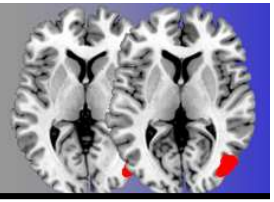
Overview

1. Costs and Benefits Overview
2. Calculating Aliasing Patterns
3. Simulation Study
4. Unprocessed HCP Data

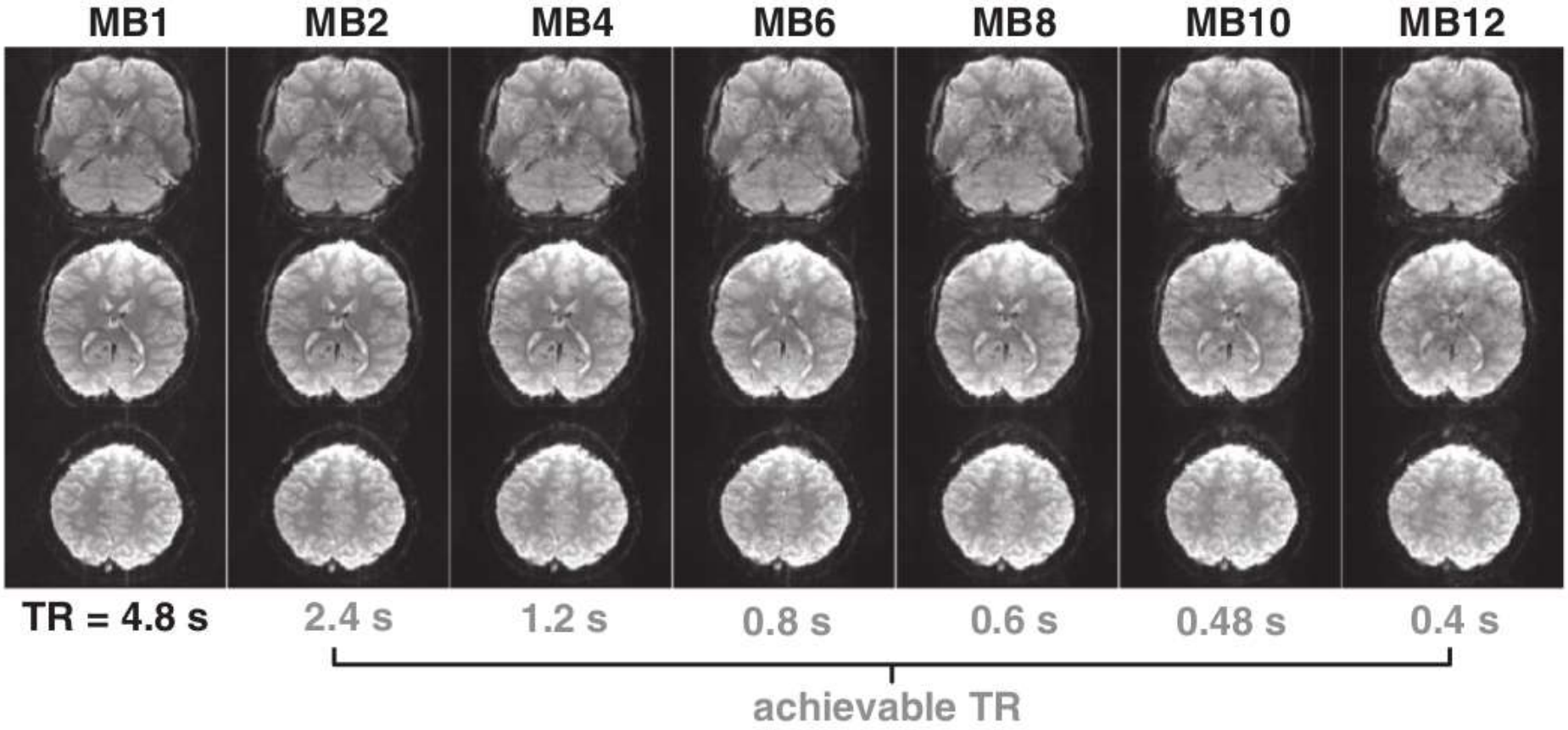


1. COSTS AND BENEFITS OVERVIEW

Reconstruction error

- Xu et al 2013 HCP Consortium:

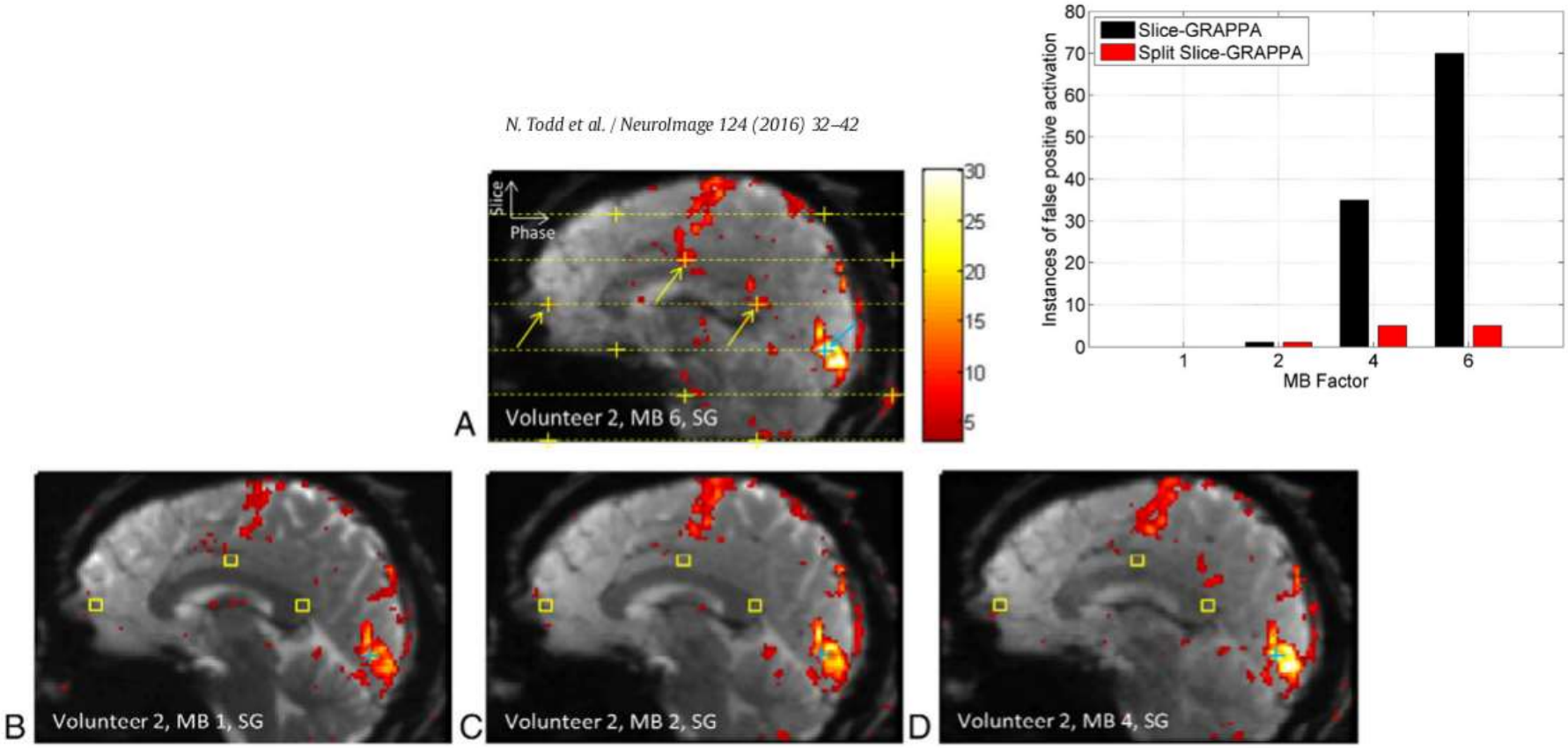
Note: MB factor = SMS factor



Costs

- In acquisition literature, reconstruction error quantified using
  - G-factor: noise amplification (variance)
  - L-factor: signal leakage (bias)
- Here, we focus on test statistics.
- Two reconstruction methods:
  - Slice-GRAPPA (Setsompop 2012)
  - Split slice-GRAPPA (Cauley 2014) = Leak Block

Slice leakage



Benefits in fMRI

- SMS decreases TR
- Benefits “indirect” because power in BOLD < 0.2 Hz (Nyquist 2.5 s)
- Boosts effective sample size – decreases SE
- Improve ability to separate physiological noise – ICA, lo-pass filtering

Higher test statistics

- Higher test statistics and/or larger number of activated voxels:
  - Task fMRI:
    - Chen et al 2015
    - Boyacioglu et al 2015
    - Demetriou et al 2015
    - Todd et al 2016, 2017
  - Resting state fMRI:
    - Feinberg et al 2010
    - Preibisch et al 2015

Todd et al 2016

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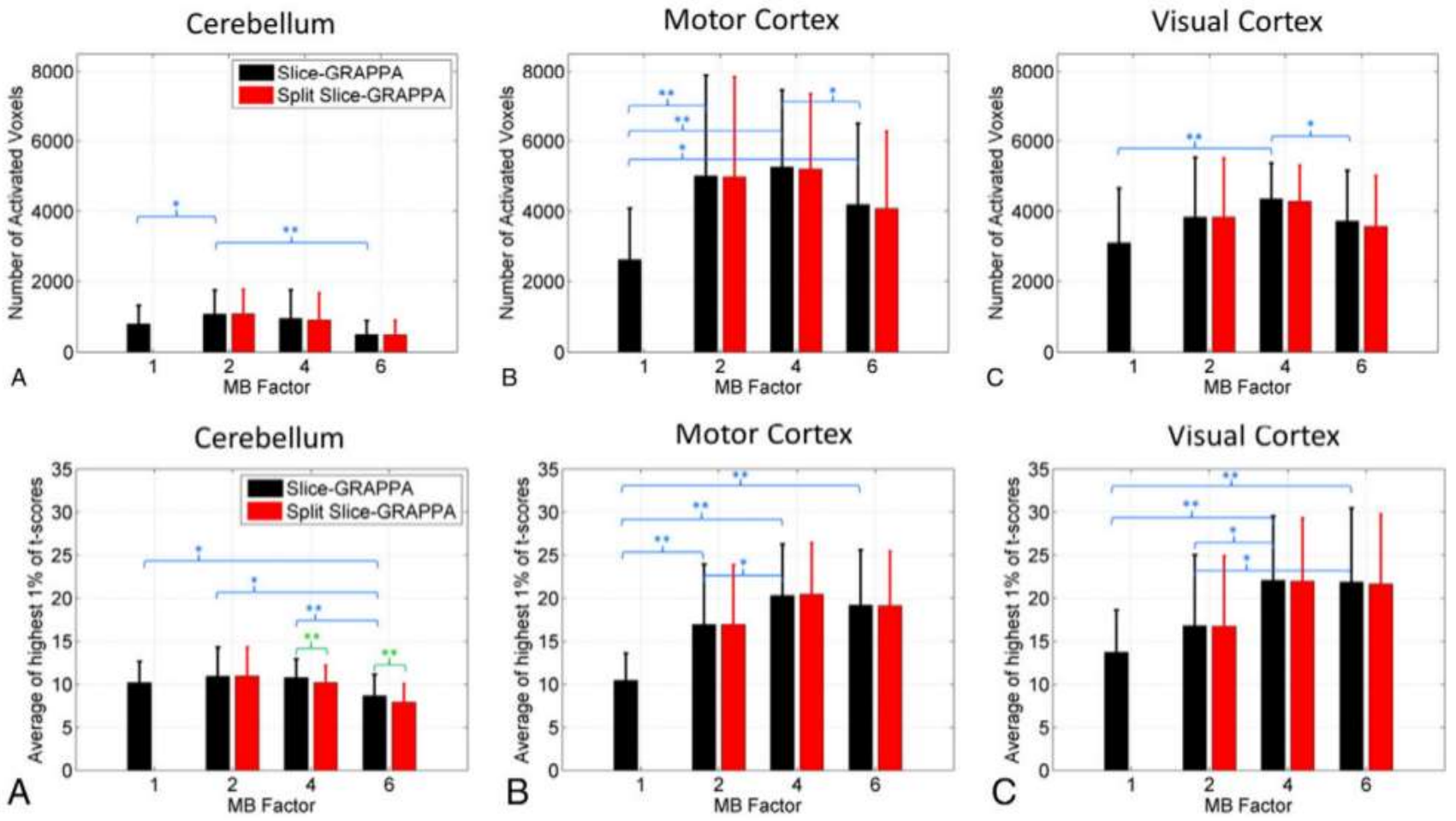
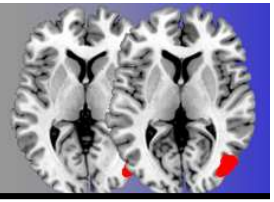
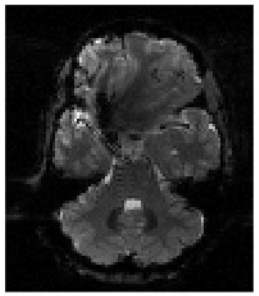
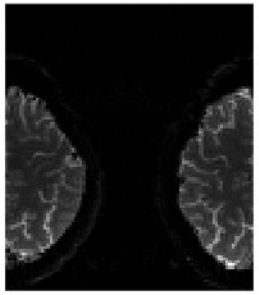




2. CALCULATING ALIASING PATTERNS

Example SMS = 2

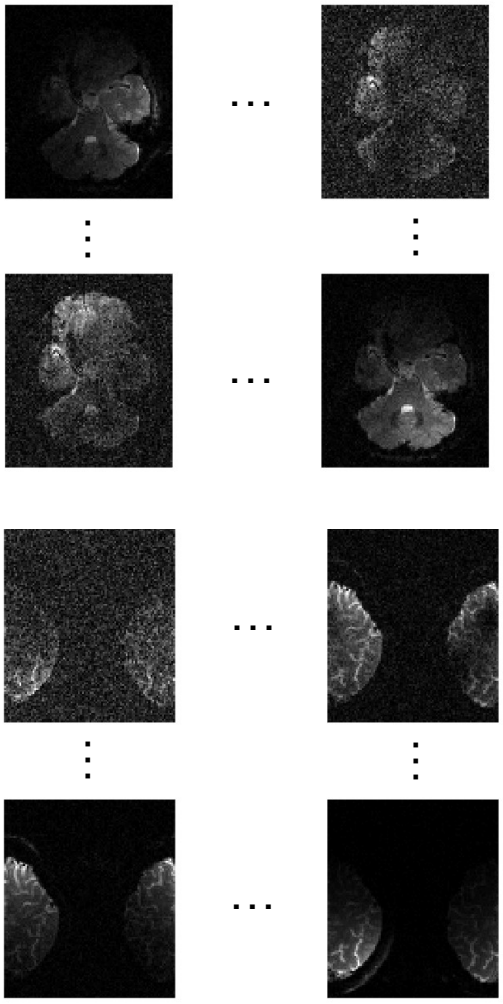




signal, FOV/2

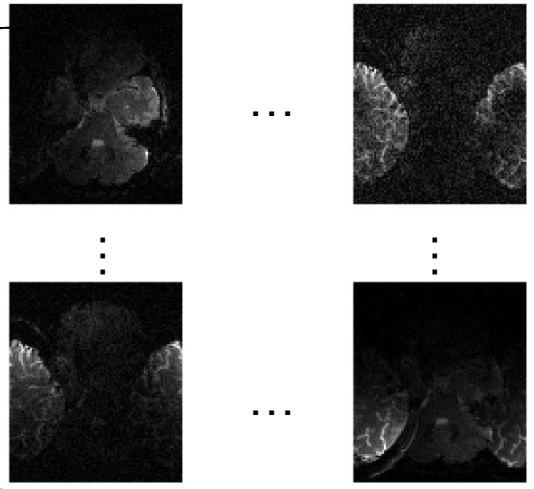
32 channels

sb calibration image

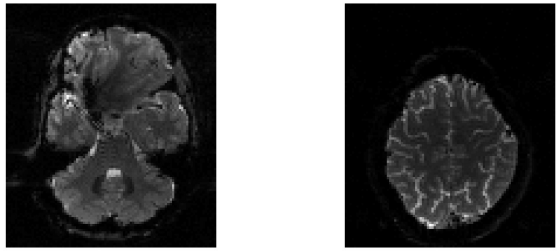


collect hundreds…

time series of multiband slices



Slice-Grappa, SOS



Ex: SMS = 8, FOV/3

- Suppose 72 slices, SMS = 8
- 72 / 8 = 9 packets
  - Slice 1 = packet 1
  - …
  - Slice 9 = packet 9
  - Slice 10 = packet 1…
- Packet 1: Slices 1, 10, 19, 28, 37, 46, 55, 64
- FOV/3 with 90: (1,1,1) aliased to (1,31,10), (1,61,19), (1,1,28), (1,31,37), (1,61,46), (1,1,55), (1,31,64)

LH Motor Cortex

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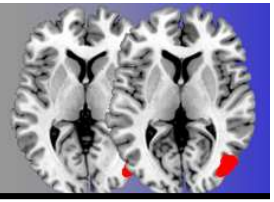

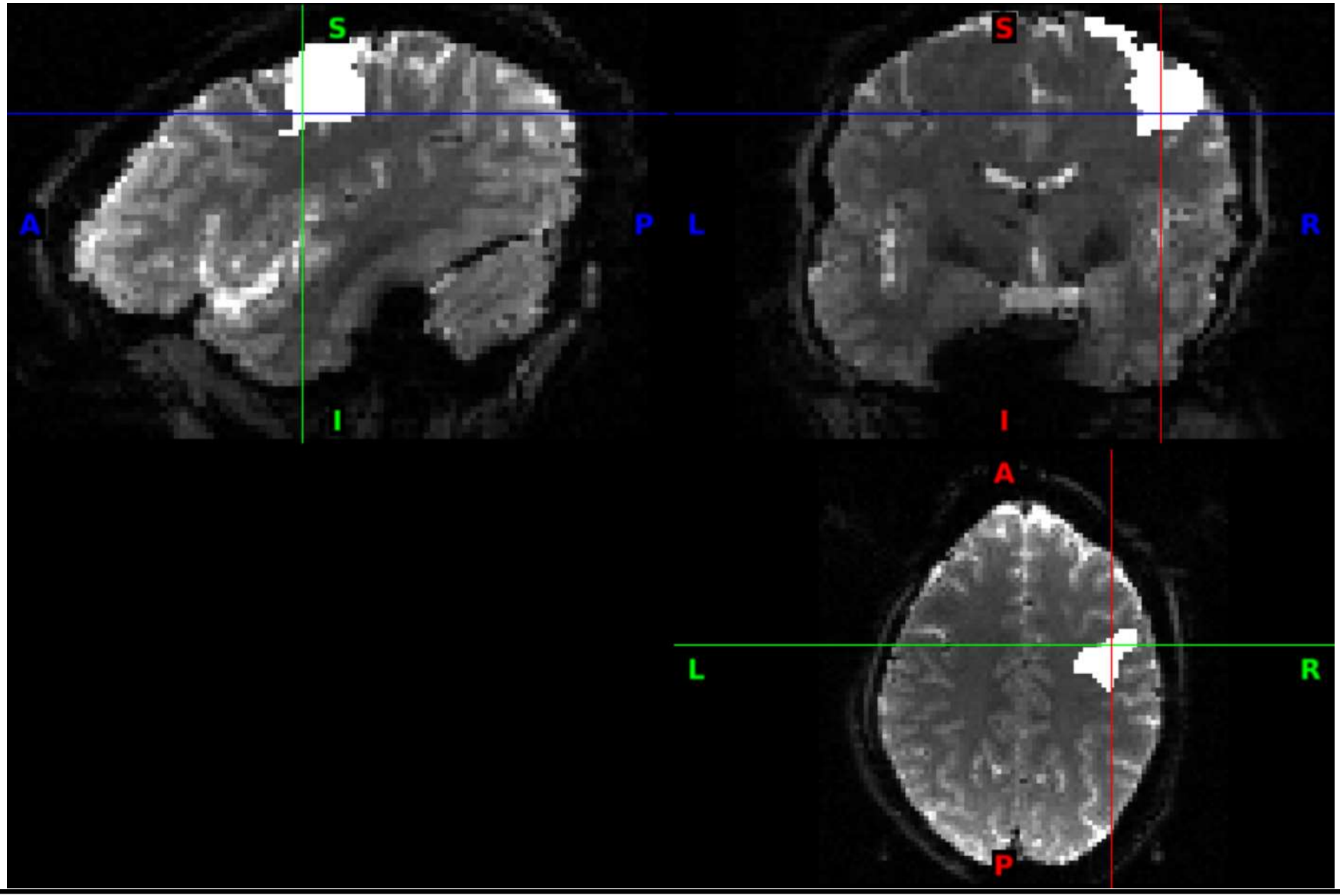

Regional aliasing

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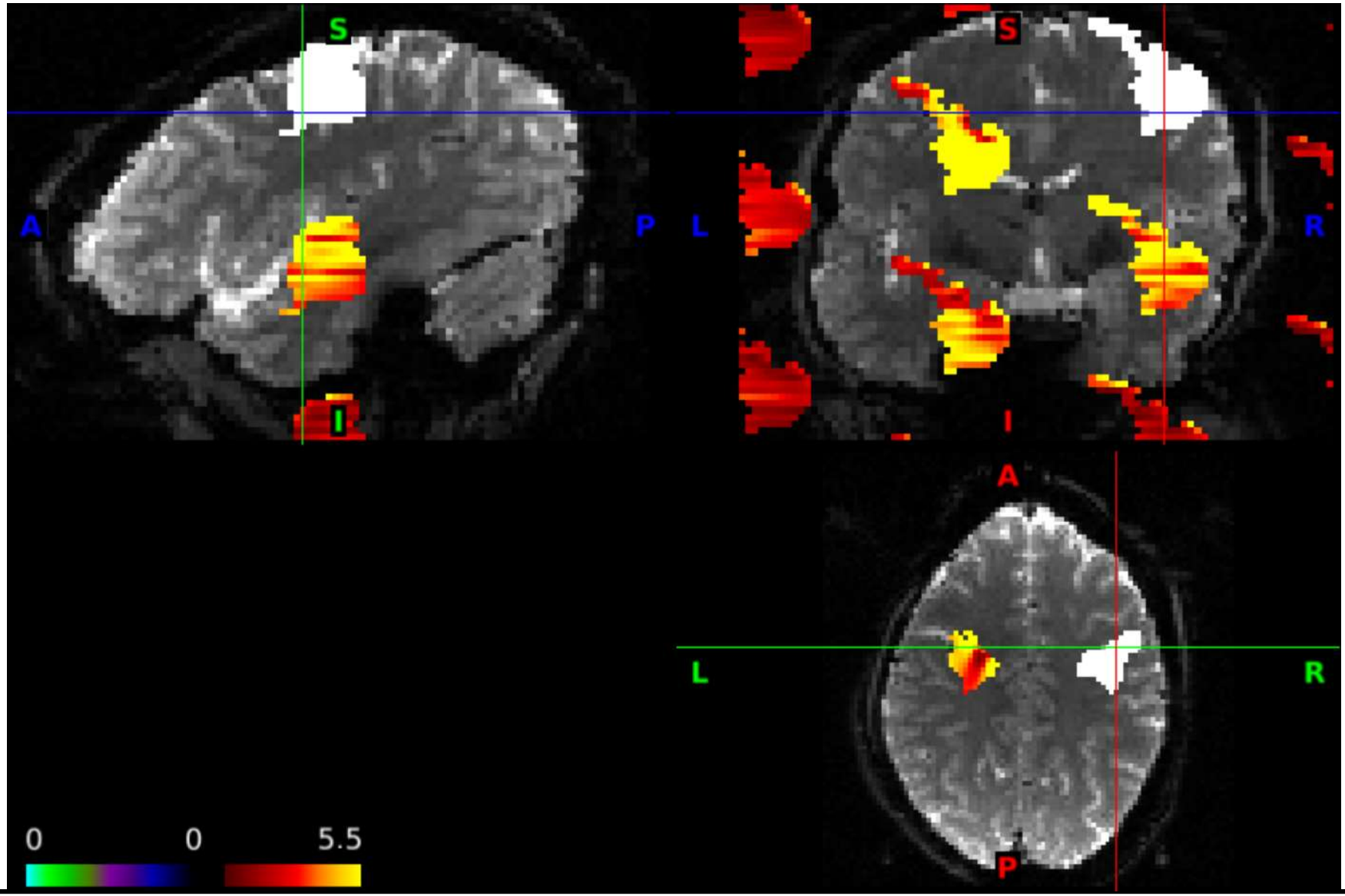
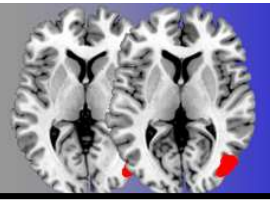


Regional aliasing

- Realized leakage has stochastic component due to measurement error
- B0 inhomogeneities and gradient non-linearities
- Motion correction
- Registration to MNI
- Predicting aliasing in processed data and group analyses is difficult



Joint work:
Mary Kociuba, University of Washington, Seattle, WA
Dan Rowe, Marquette University, Milwaukee, WI

3. SIMULATION STUDY: SENSITIVITY & SPECIFICITY

Quantify tradeoffs

- Larger test statistics in presence of bias = false positives
- Bias from signal leakage:
  - Slice leakage – spurious regions
  - Smoothing leakage – overestimate region with true activation
- Smoothing interact with SMS?

Simulation Design

- Sensitivity: correctly reject null hypothesis (1 – false negatives)
- Specificity: correctly fail to reject null hypothesis (1 – false positives)
- Factorial design motivated by HCP motor task:
  - FOV/3 or 0
  - SMS: 1, 4, 8
  - Scan duration: 120 s, 240 s, 480 s
  - 0 versus 6 mm FWHM smoothing

Slice-GRAPPA

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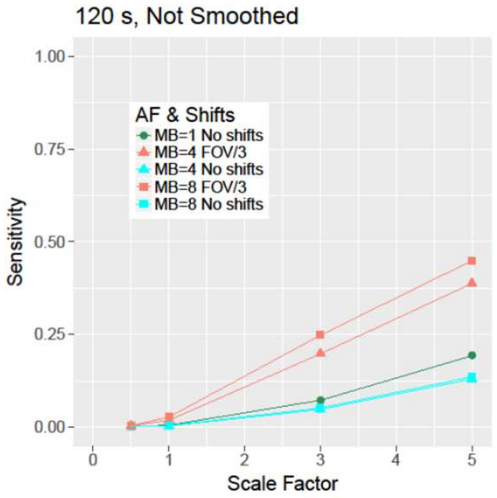

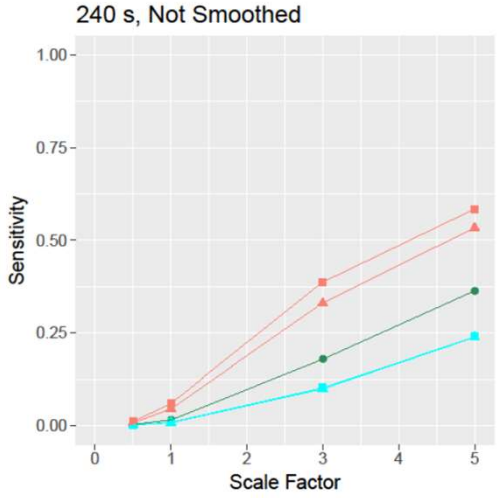

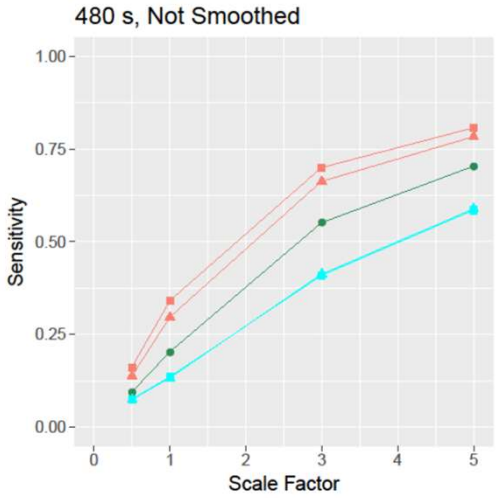

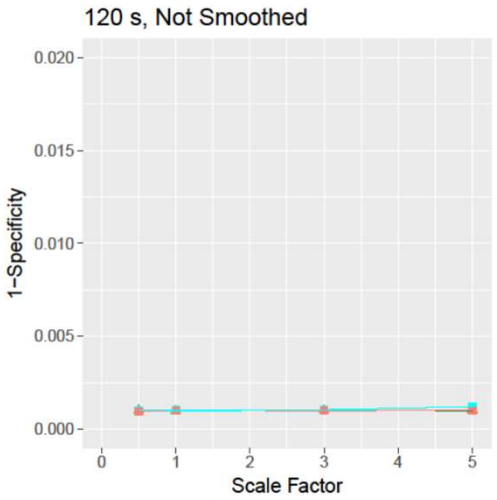

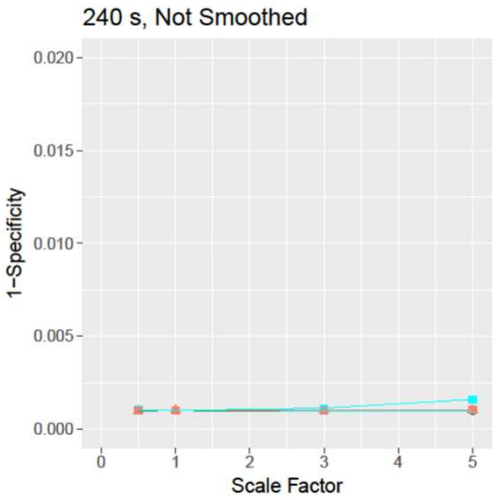

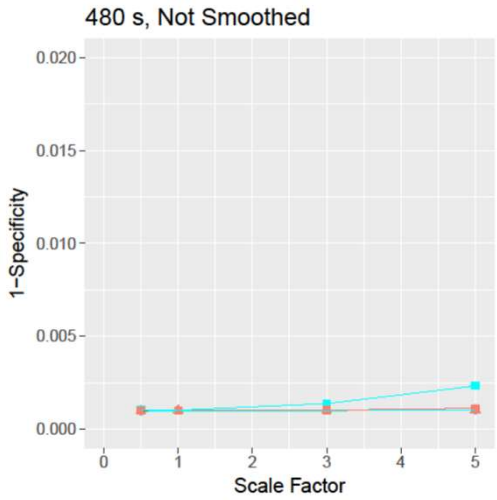

Slice-GRAPPA

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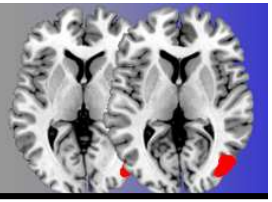

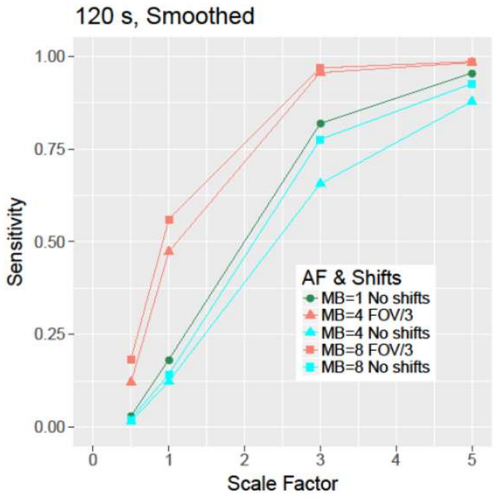

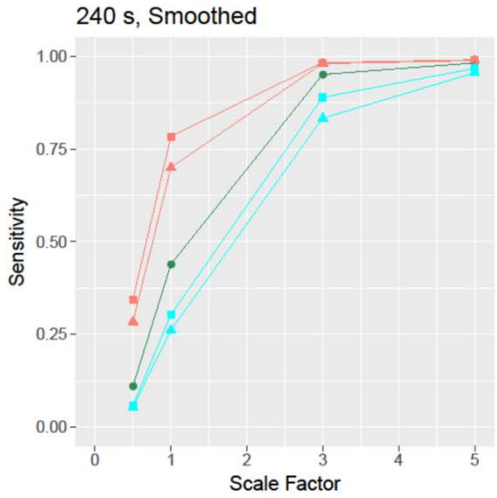

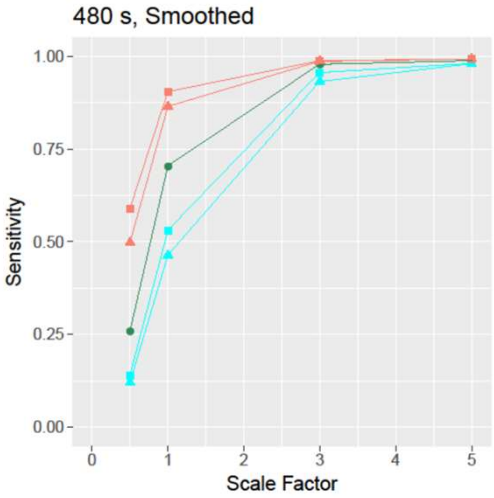

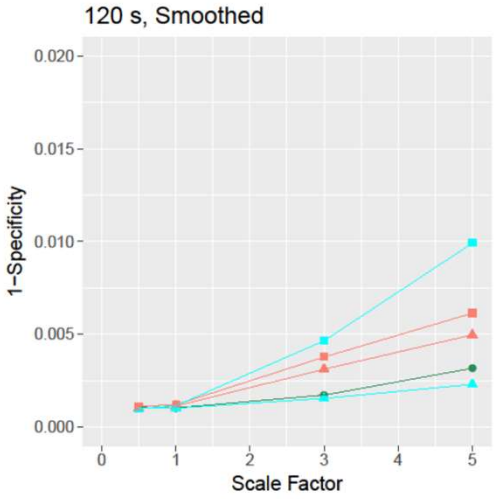

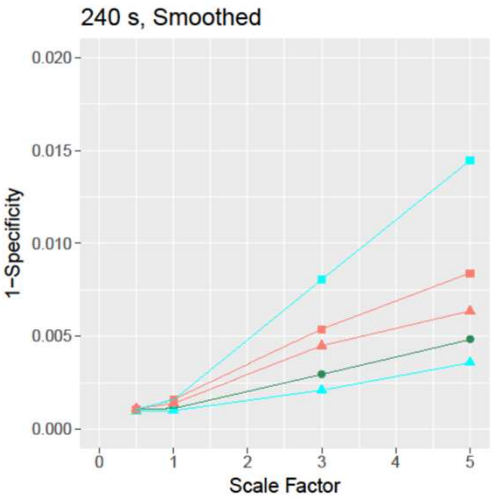

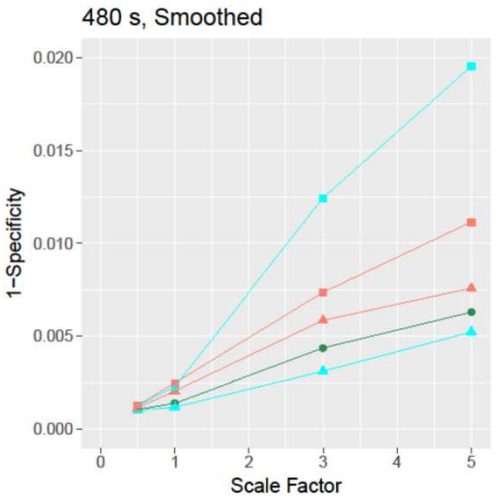

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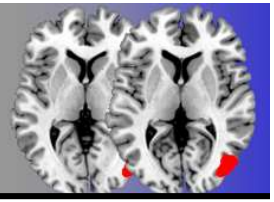
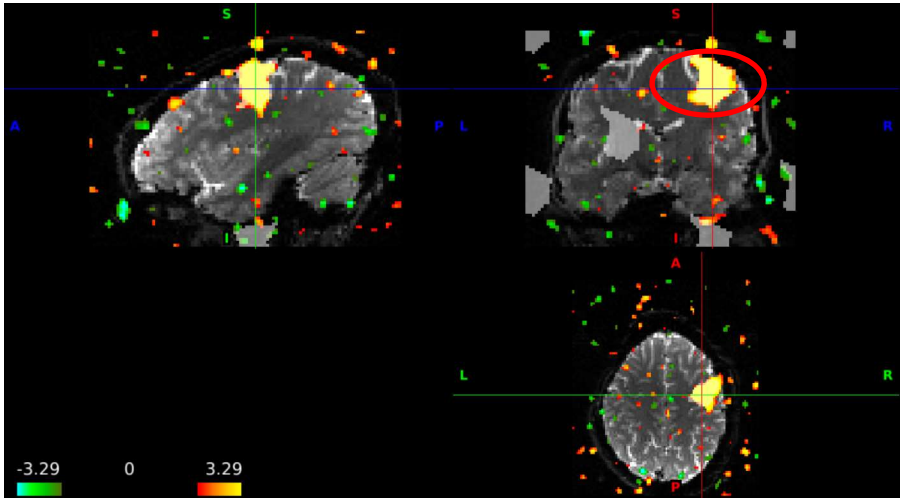
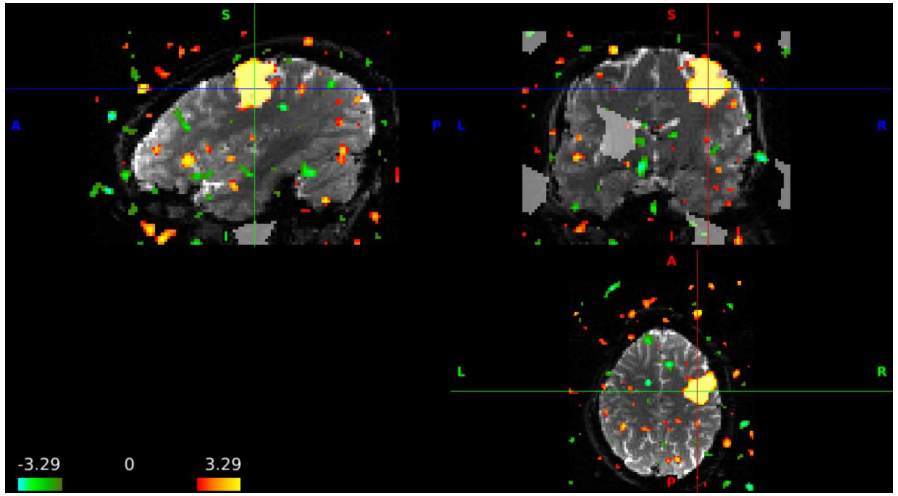


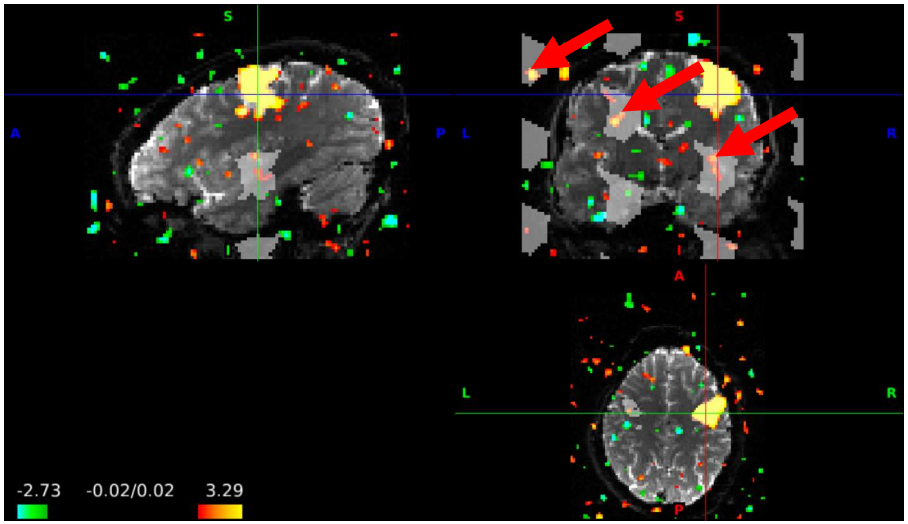
Iter 1 | Iter 2

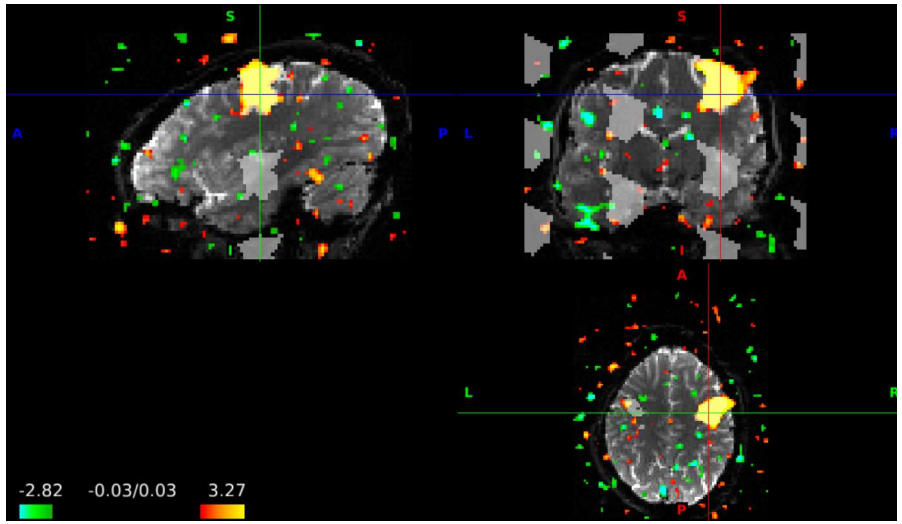
SMS 4





SMS 8





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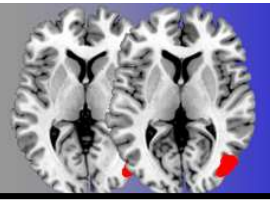

Iter 1 | Iter 2

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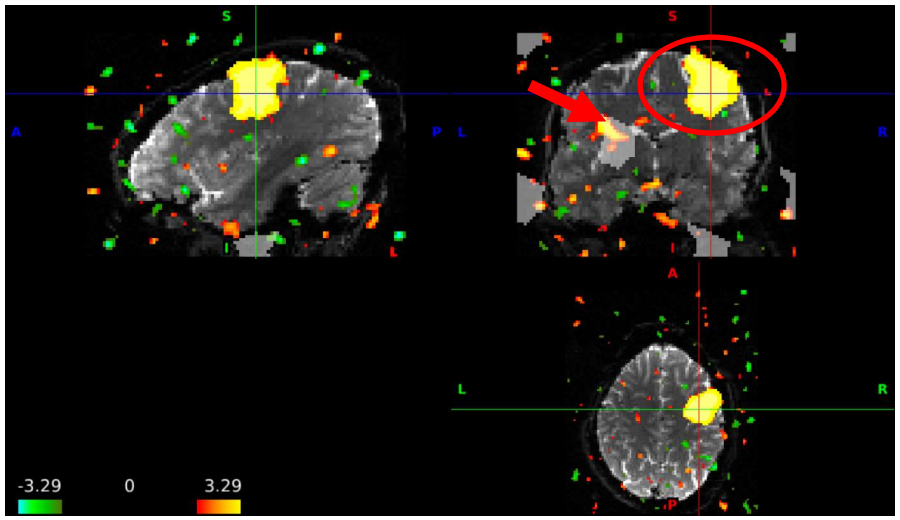

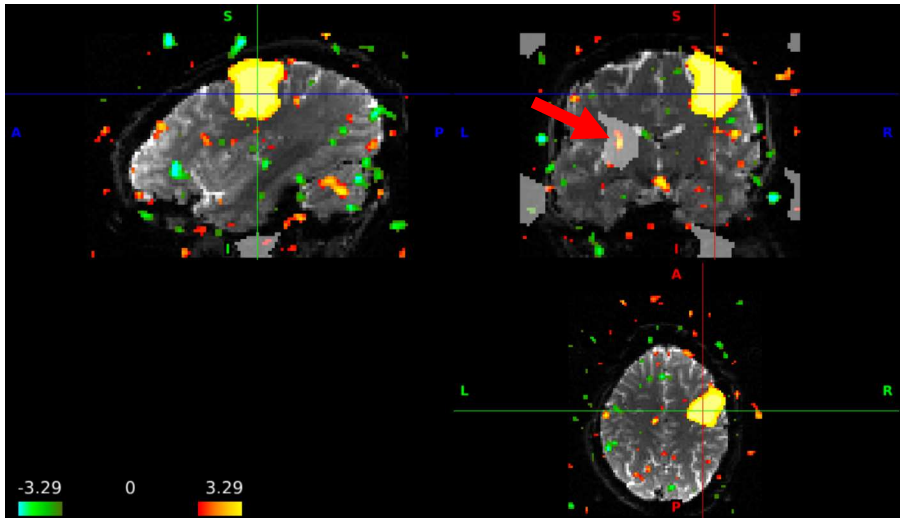

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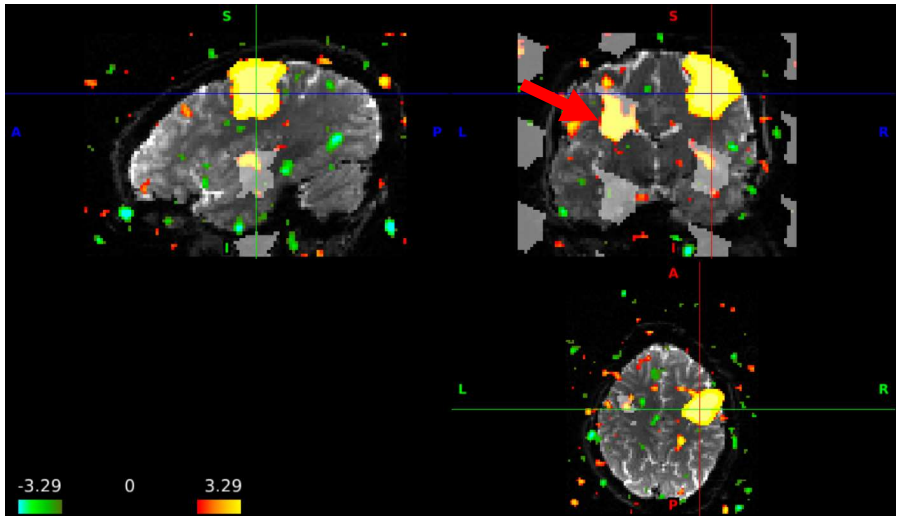

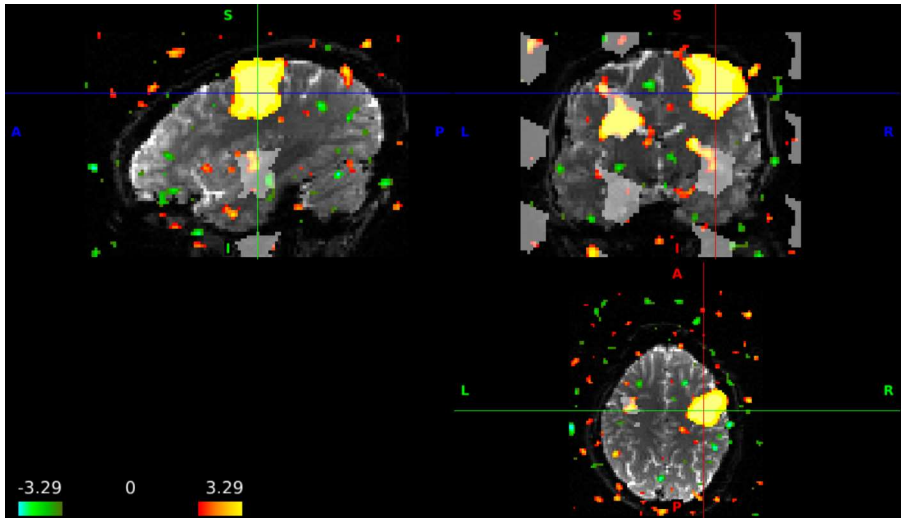

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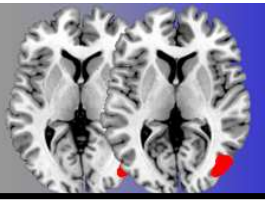
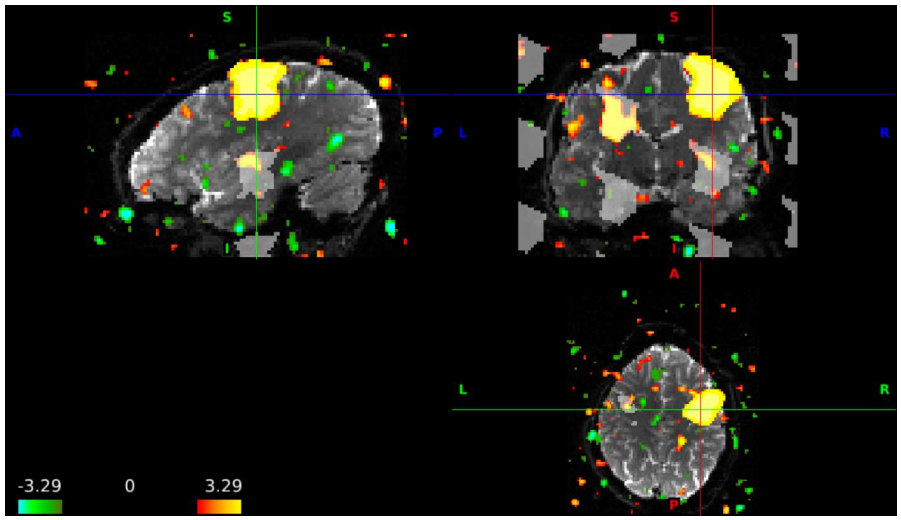
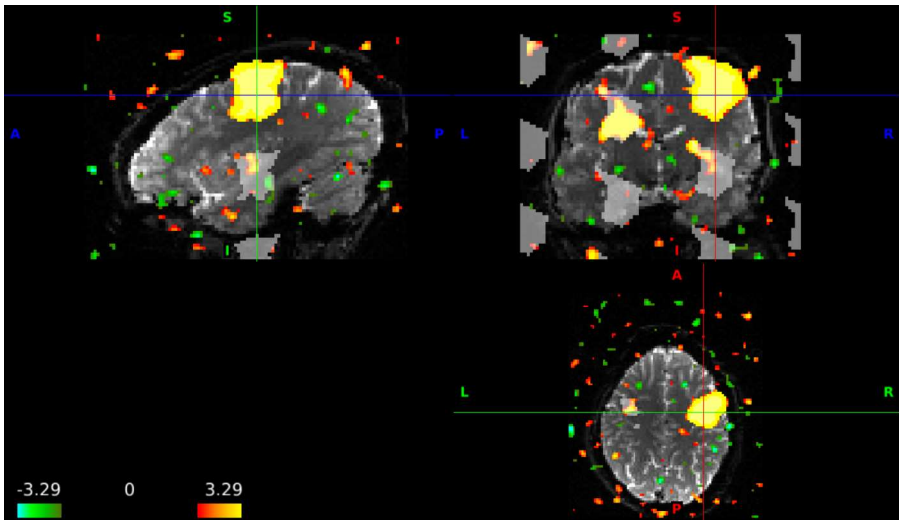


Iter 1 | Iter 2

SG SMS 8





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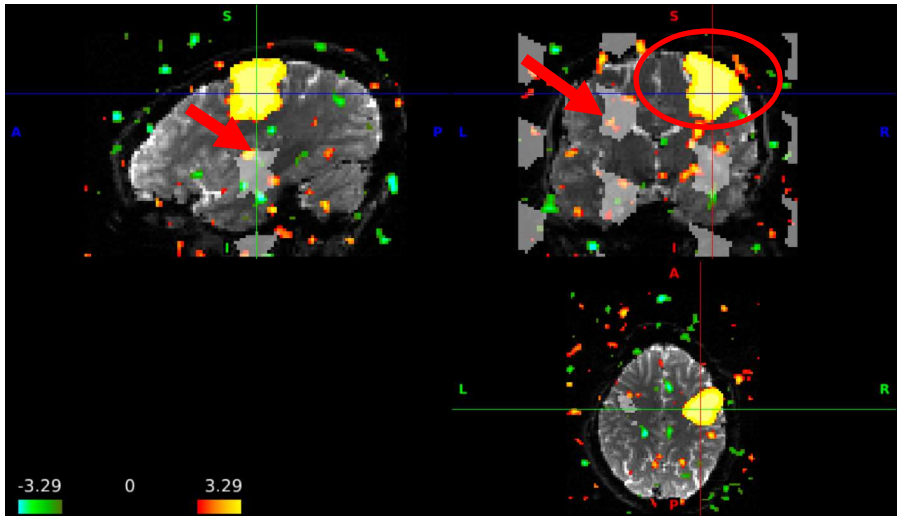

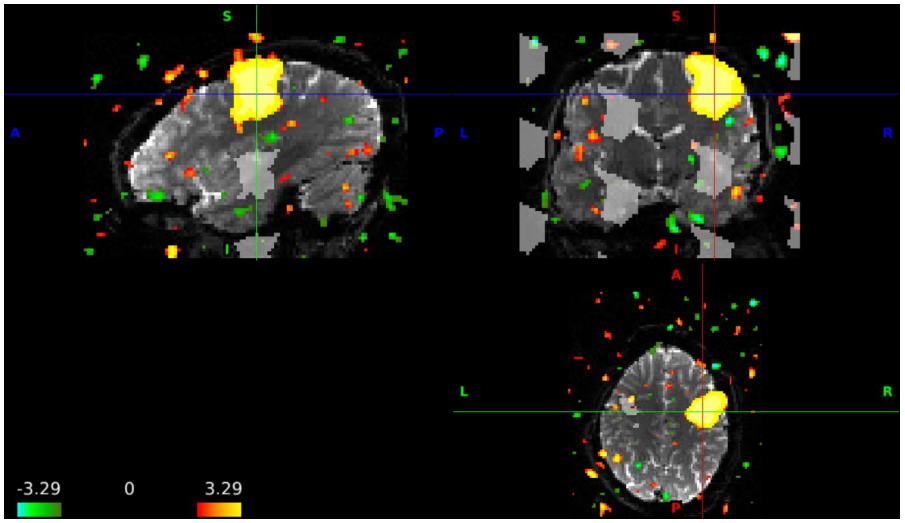

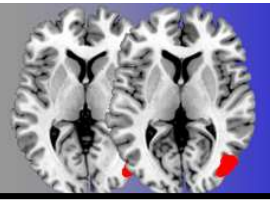

Joint work:

Mary Kociuba, University of Washington, Seattle, WA

Dan Rowe, Marquette University, Milwaukee, WI

4. UNPROCESSED HCP DATA

HCP task fMRI

- SMS = 8
- TR = 0.72 s
- Blipped-CAIPI: FOV/3
- Slice-GRAPPA reconstruction
- 2 runs: RL PE direction, LR
- Voxel size: 2 x 2 x 2
- Single-subject analyses motor task

HCP leakage?

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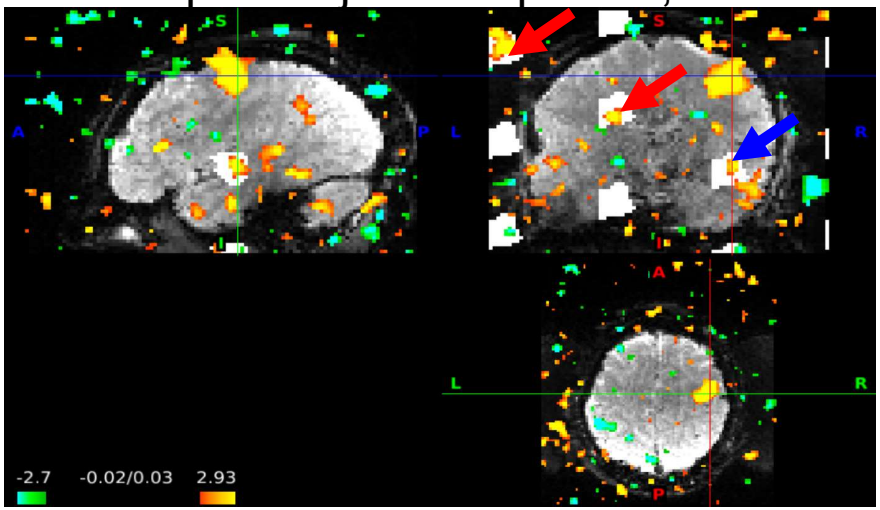
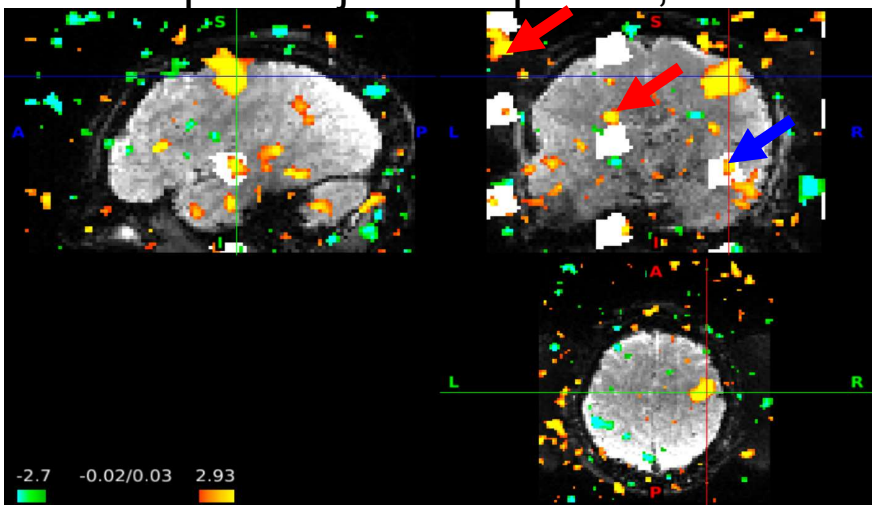
Example subject: LR predict, LR PE



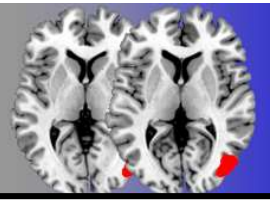
Example subject: RL predict, LR PE



- Analysis for both LR and RL runs, combined results

	$P_{matched}$	$P_{mismatched}$	*Difference*
1	0.023	0.020	0.003
2	0.027	0.017	0.010
3	0.066	0.050	0.016
4	0.050	0.050	0.000
5	0.036	0.026	0.009
6	0.014	0.009	0.005
7	0.014	0.014	0.000
8	0.028	0.027	0.001
9	0.041	0.049	-0.007
10	0.014	0.010	0.004
11	0.031	0.029	0.002
12	0.035	0.025	0.010
13	0.043	0.022	0.020
14	0.039	0.024	0.015
15	0.026	0.012	0.014
16	0.034	0.050	-0.015

Table 1: The proportion of voxels with $z > 2.326$ in the predicted aliased regions (matched) and in regions that are aliased using the opposite PE direction (mismatched). A larger proportion in $P_{matched}$ is considered evidence of slice leakage. One-sided Wilcoxon signed rank test: $p = 0.01$.



Joint work:
Mary Kociuba, University of Washington, Seattle
Dan Rowe, Marquette University, Milwaukee, WI

4B. HCP DATA: NOISE AMPLIFICATION

Residual variance: ex 1

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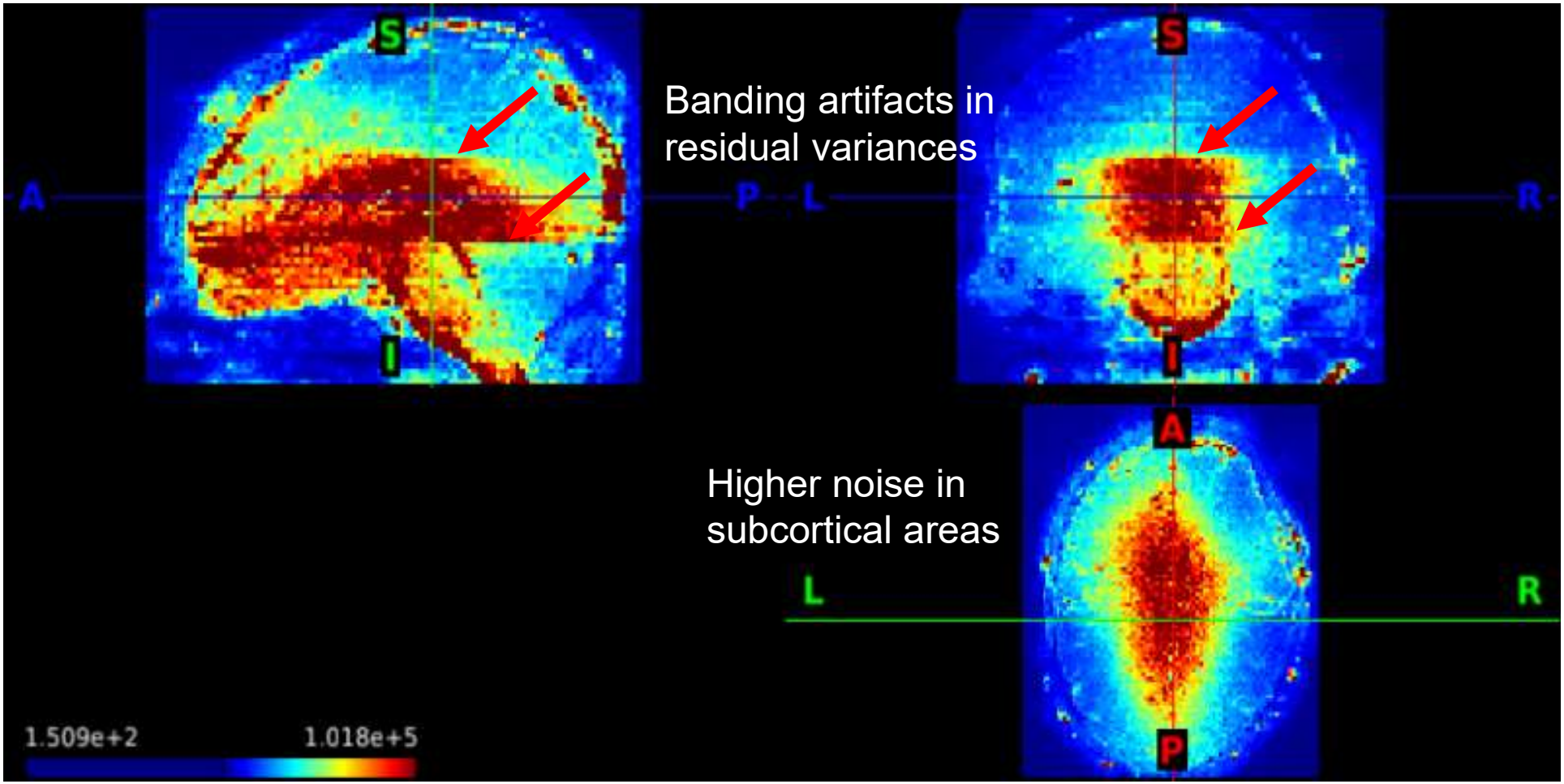

Residual variance: additional examples

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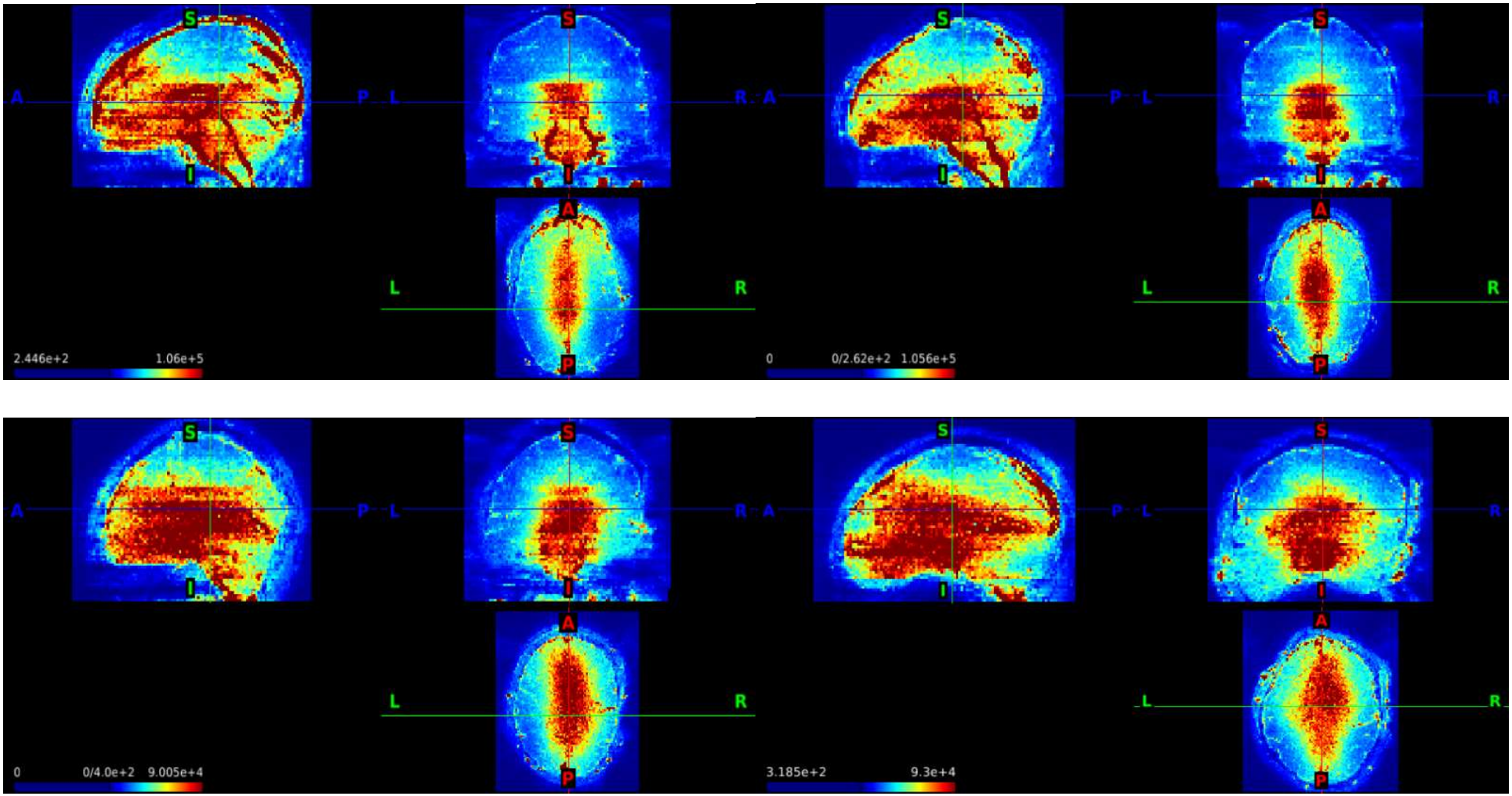

Discussion

- SMS can lead to higher test statistics
- SMS creates bias:
  - slice leakage
  - exacerbates smoothing leakage
- SMS improves sensitivity but decreases specificity
  - use moderate acceleration
  - minimal smoothing
- Split slice-GRAPPA dramatically decreases leakage, few costs?

Discussion, cont.

- Preprocessed HCP: expect less leakage
  - minimal smoothing and gray matter areas
- Impacts in group studies?
- Residual noise artifacts likely to persist in split slice-GRAPPA
  - impacts estimated activation regions?
- SMS continues to evolve:
  - alternative FOV shifts (e.g., incoherent aliasing Zhu 2014), reconstruction methods, 3D acquisitions (e.g., wave-CAIPI Bilgic 2015)

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