Reducing susceptibility-induced signal loss in echo planar imaging using a shim insert coil at 7T: Implication for BOLD fMRI

Tae Kim[1], Tiejun Zhao[2], Yoojin Lee[1], Piotr Starewicz[3], Hoby Hetherington[1], and Jullie Pan[1]

[1]Radiology, University of Pittsburgh, Pittsburgh, PA, United States,
[2]Siemens Medical Solution USA, INC., Siemens MediCare USA, Pittsburgh, PA, United States,
[3]Resonance Research Inc., Billerica, MA, United States

Introduction

- GE- EPI is commonly used for fMRI studies due to its high sensitivity to BOLD signal changes.
- However, GE-EPI acquisitions are also sensitive to the macroscopic local field inhomogeneity, which induces intravoxel dephasing and causes significant signal dropout, especially at high magnetic field.
- This signal loss degrades fMRI studies in brain regions adjacent to air cavities, particularly in the ventral prefrontal and lateral temporal lobe, which are important regions in psychiatric studies.

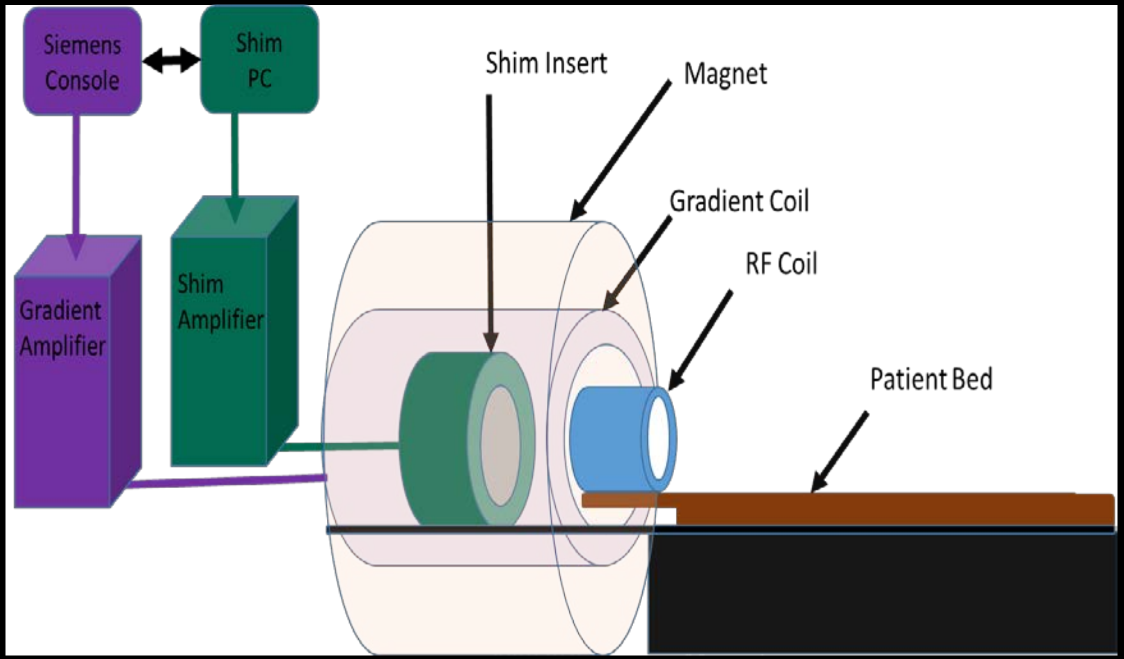
Introduction

- Most systems to date are equipped with only 1st and 2nd degree shims which are insufficient to correct these susceptibility effects.
- The Z-shim method has been proposed to for correct for some of the field distortion. However, this technique reduces the temporal resolution significantly.
- To overcome these limitations, higher degree shims (3rd, 4th and above) are required.
- In this study, we demonstrate the improvement in signal retention using a very high order shim insert coil (2nd-4th degree shims) at 7T using GE-EPI acquisitions.

Methods

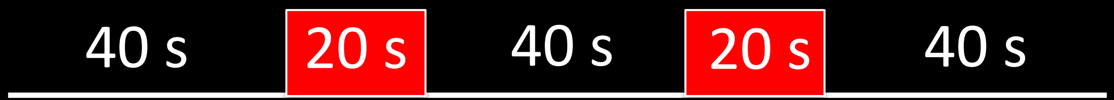
- Four healthy volunteers were studied on a 7-T Siemens scanner using an 8 channel inductively decoupled ^{1}H transceiver array.
- A 28 channel shim insert coil with a 38 cm ID consisting of Z0, all 2nd-4th degree shims and partial 5th and 6th degree shims with 5A shim supplies (Resonance Research Inc.) was used for higher degree/order shimming. B0 mapping was performed using a 6 time point (0.5 to 8ms evolution times) multi-slice measurement. The shim values were calculated using a non-iterative least squares algorithm.

Very High Order Shim Insert



Methods

- A single-shot GE-EPI was acquired with FOV = 25.6×25.6 cm^2, matrix size = 96×96, slice thickness = 3 mm (voxel size = $2.7 \times 2.7 \times 3.0$ mm^3), TR/TE = 2 s/23 ms.
- Breath-holds were performed to increase BOLD signal throughout entire brain area.

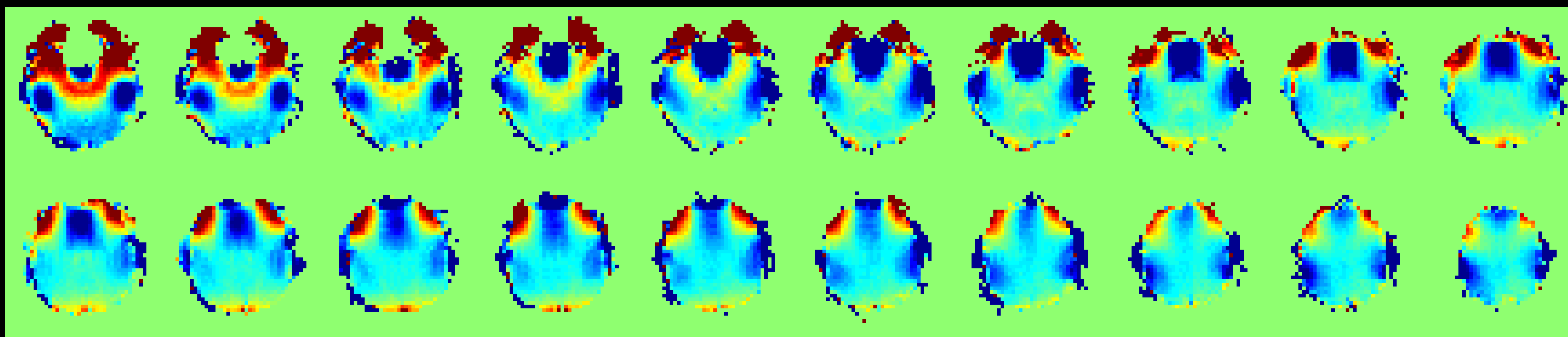


- Voxel-wise temporal-signal-to-noise (tSNR) maps were calculated by dividing the mean of the pre-stimulus period by its standard deviation for the sensitivity of GE-EPI
- Statistical analyses were performed on a pixel-by-pixel basis (p-value < 0.05) to determine for activated pixels using AFNI.
- ROIs were selected by brain parcellation using Freesurfer

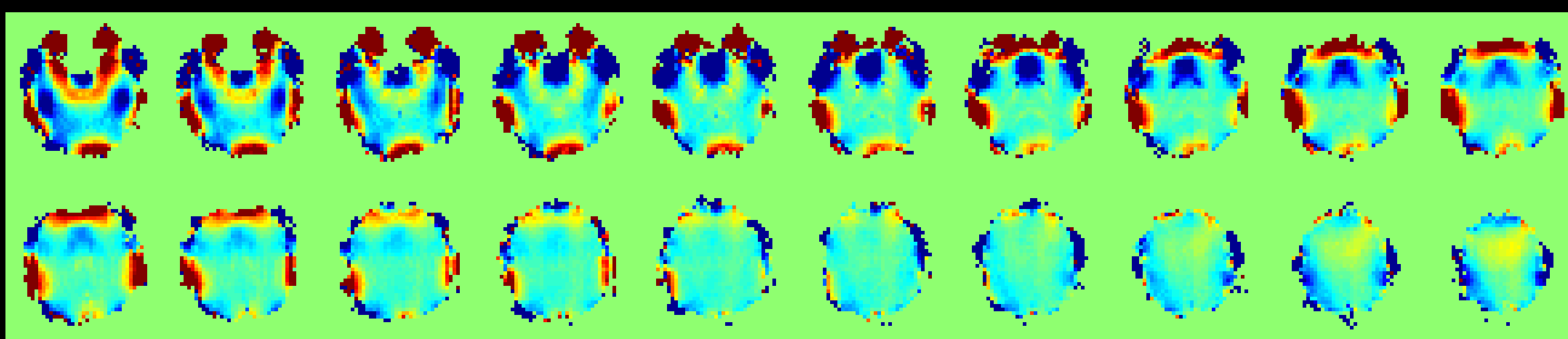
Results

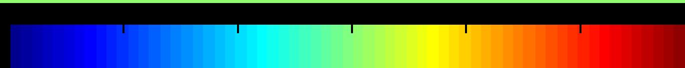
B0 map

Shim 1st & 2nd : S.D. = 24.37

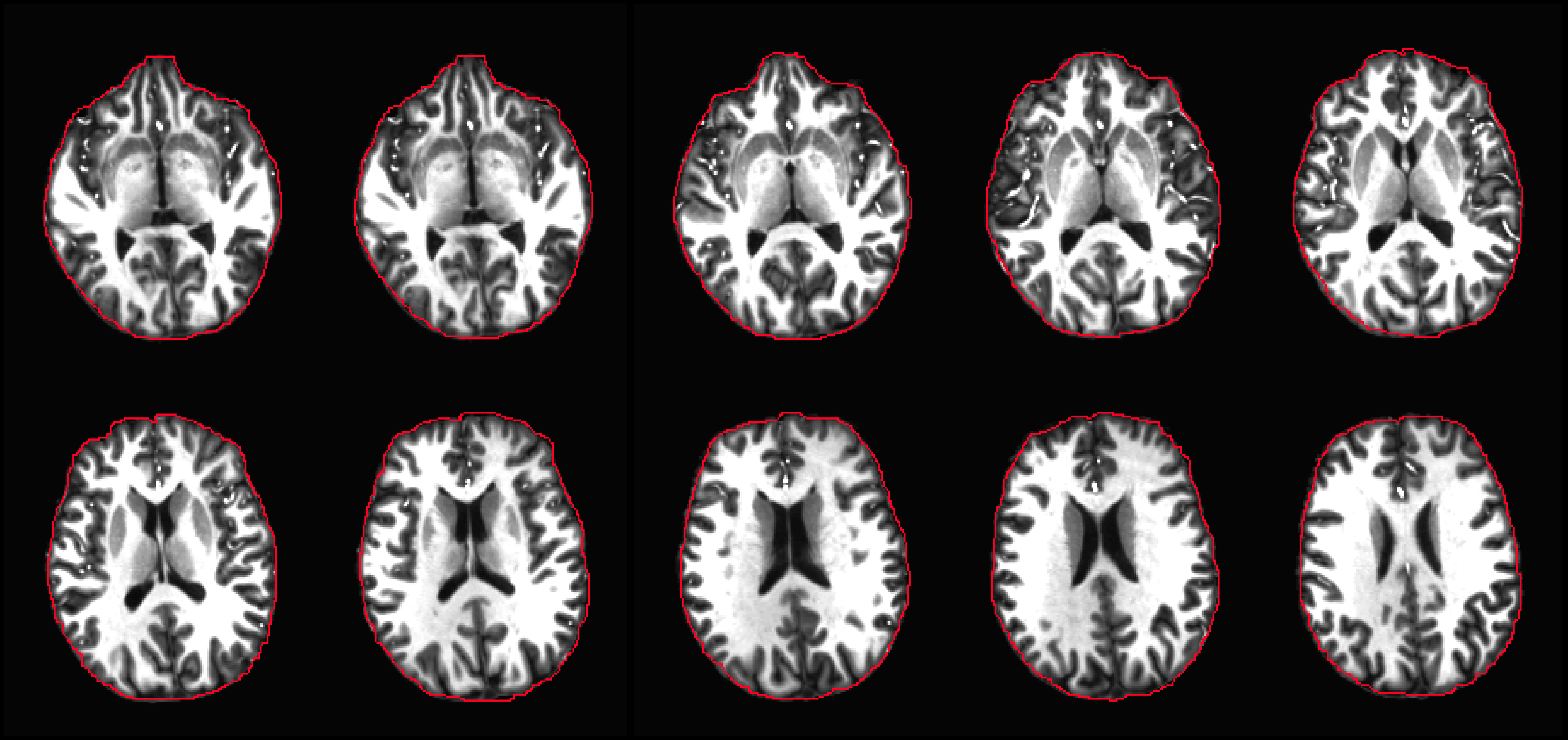


Shim 1st – 4th :   S.D. = 19.24

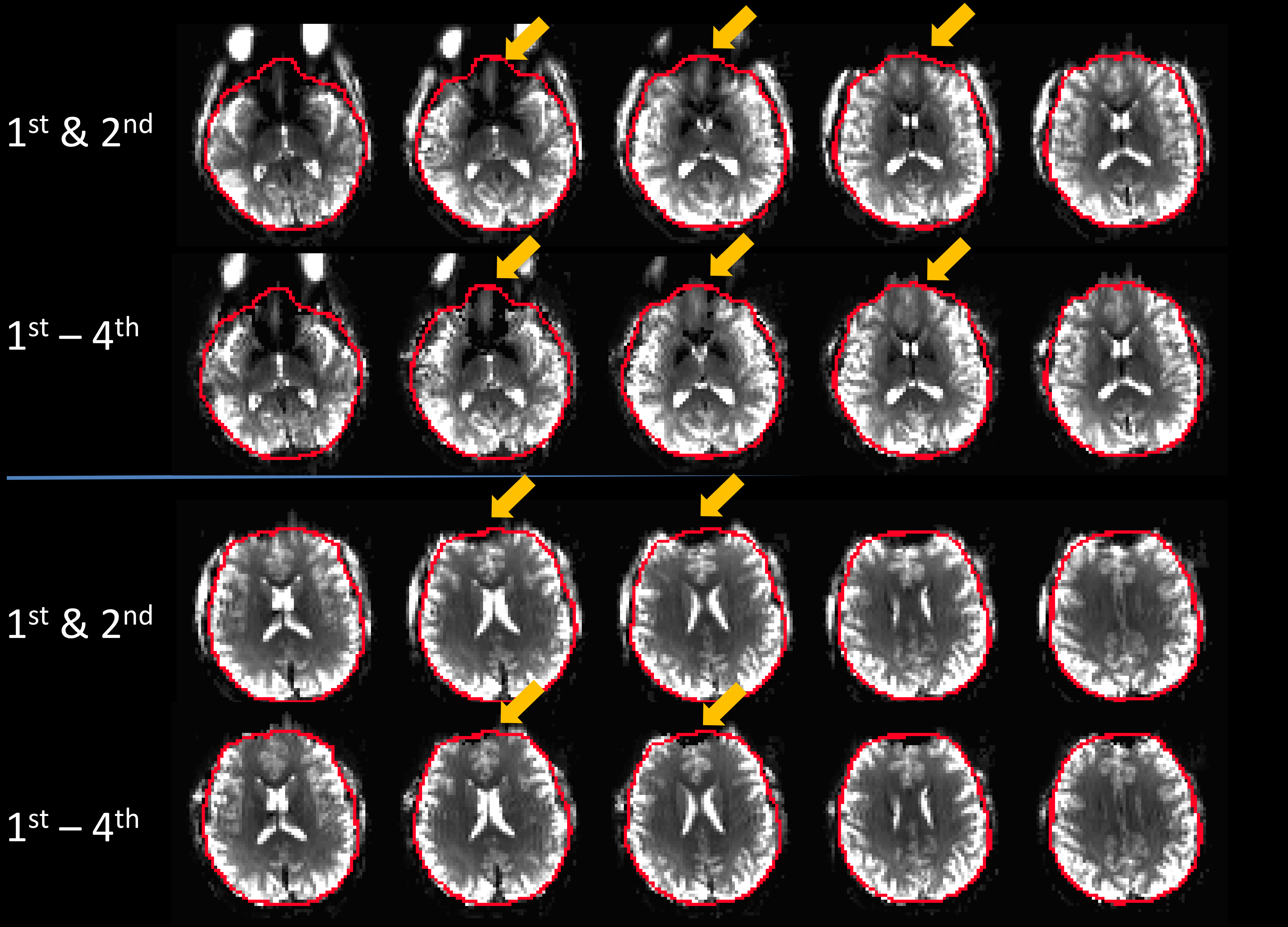


-50  -50 Hz

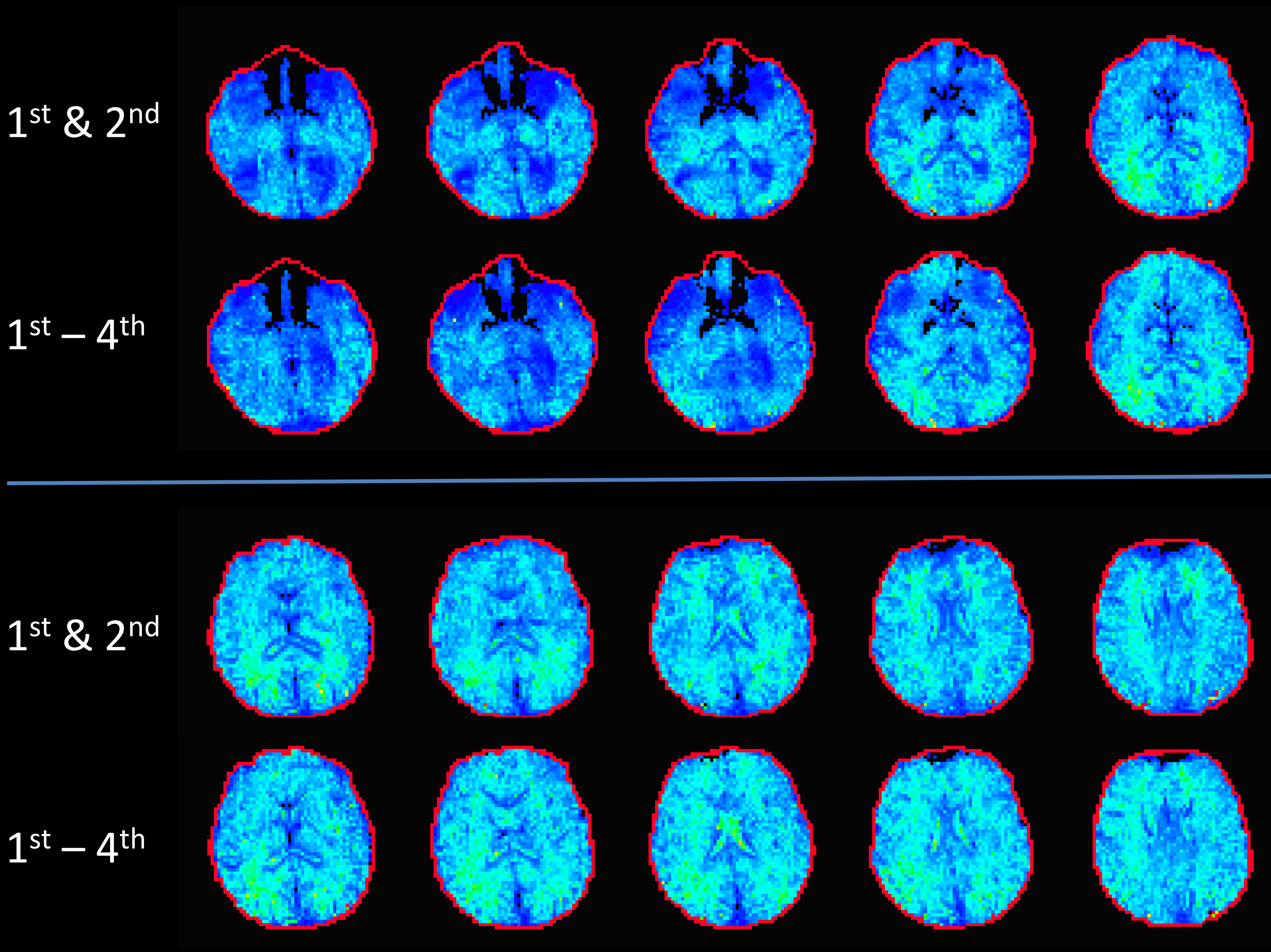
T_1-weighted image with brain extraction



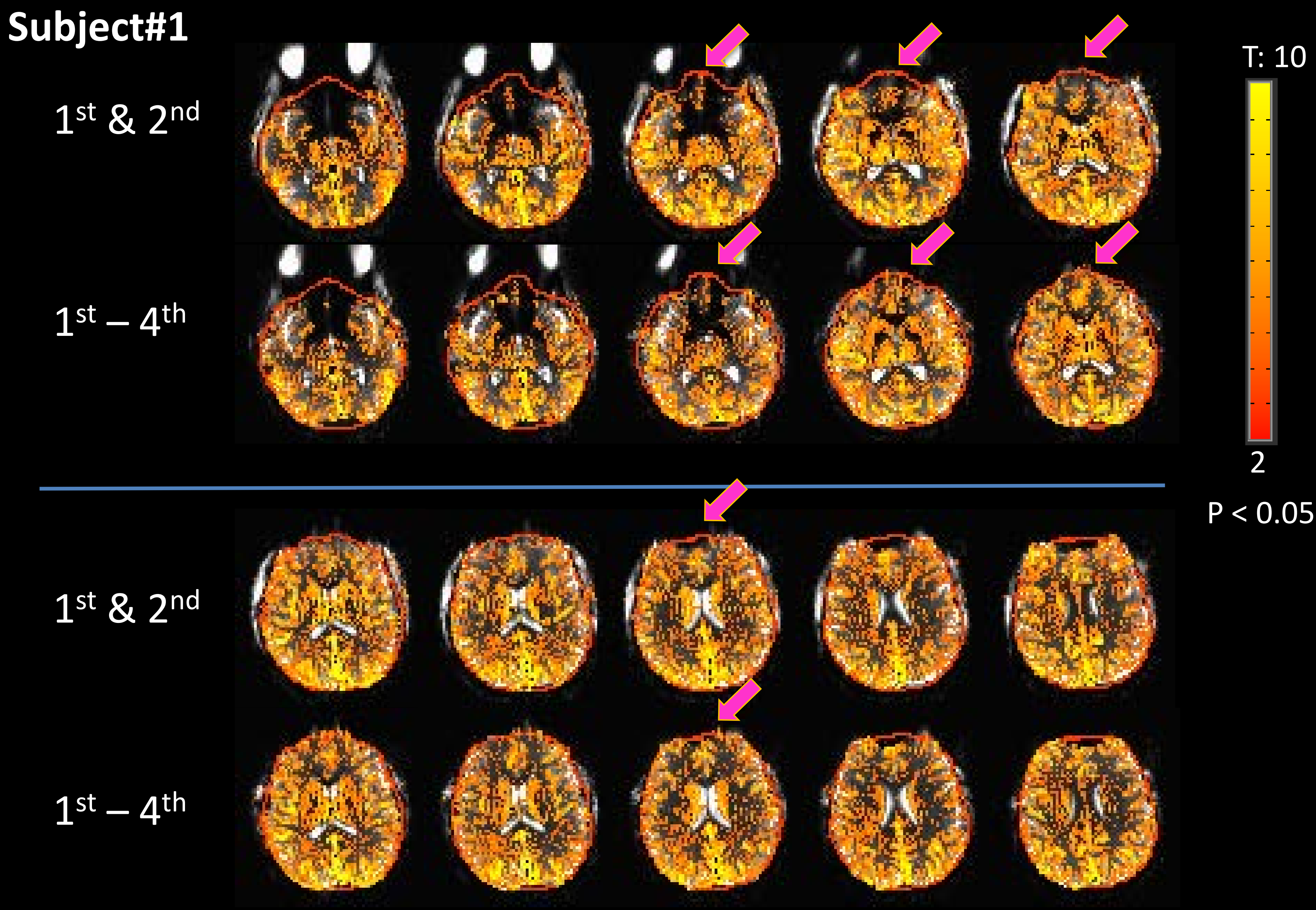
Comparison of GE EPI with 1st-2nd and 1st-4th degree shimming



Comparison of tSNR with 1st-2nd and 1st-4th degree shimming

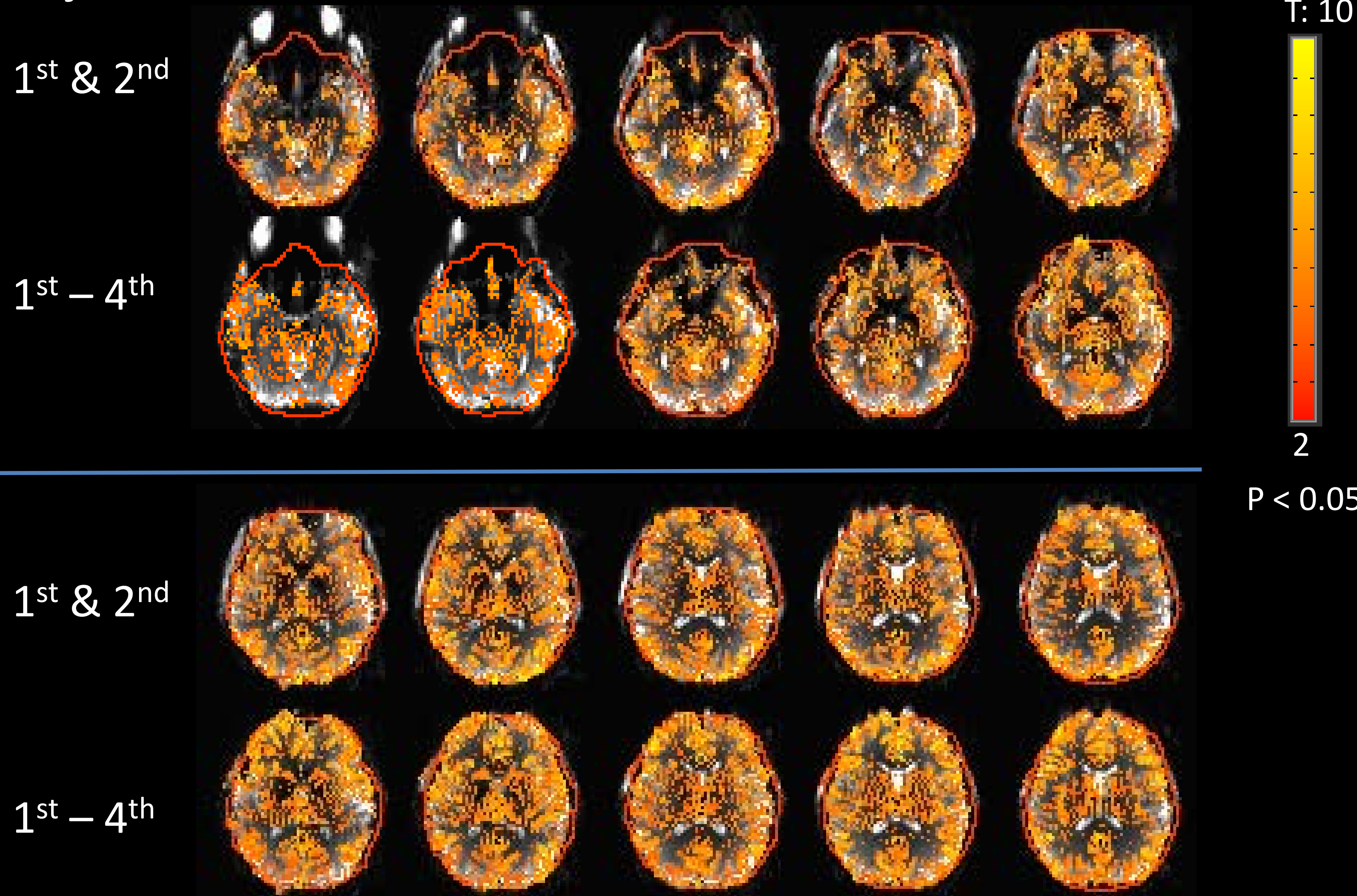


Comparison of BOLD with 1st-2nd and 1st-4th degree shimming

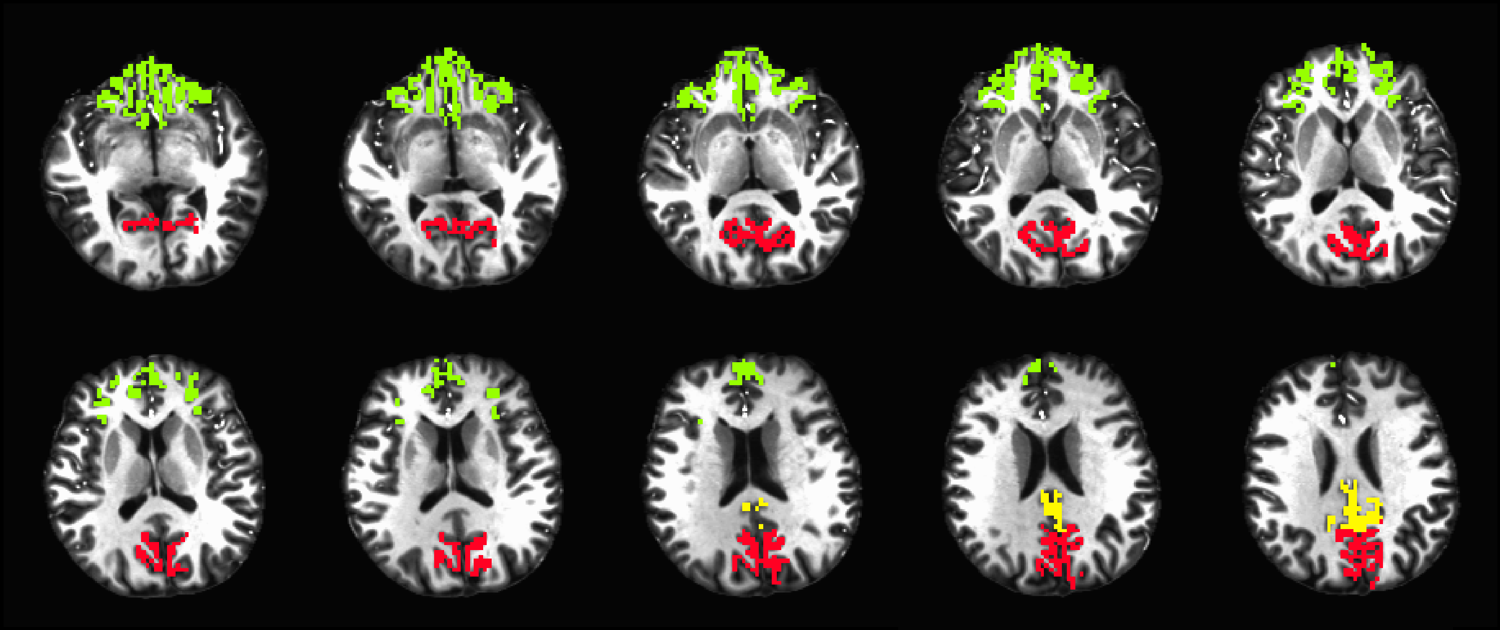


Comparison of BOLD with 1st-2nd and 1st-4th degree shimming

Subject#2



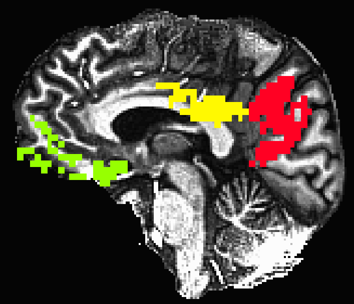
Select ROIs from brain parcellation



Orbitofrontal cortex (OFC)

Posterior Cingulate (PC)

Precuneus (PRE)



tSNR and the number of activation pixel by B0 improvement and

Subject	Global S.D.		Imprv. (%)	tSNR improvement (%)			Act. pixel improvement (%)		
	1st&2nd	1st-4th		OFC	PC	PRE	OFC	PC	PRE
1	28.05	22.04	27.27	6.7	4.33	3.82	29.5	-15.1	-17.7
2	24.37	19.24	26.66	31.1	5.54	-0.64	45.6	-2.53	-3.85
3	26.16	20.4	28.23	62.9	-1.27	12.8	73.3	42.8	39.4
4	23.90	17.61	35.71	16.3	15.3	10.5	-9.43	29.03	8.11
mean	**26.62**	**19.82**	**29.47**	**29.26**	**5.99**	**6.63**	**34.73**	**13.6**	**6.47**

Conclusion

- Higher degree/order shim using shim insert coil improves B0 homogeneity.
- Consequently, recovered signal by higher order shim increases the number of activated pixels, particularly in orbital frontal cortex.
- Our study demonstrates that higher order shimming improves fMRI detection of neural activation, especially in studies of decision making and emotional response at high magnetic field.