Complex Constant Phase Activation Model Removes Venous BOLD Contribution in fMRI

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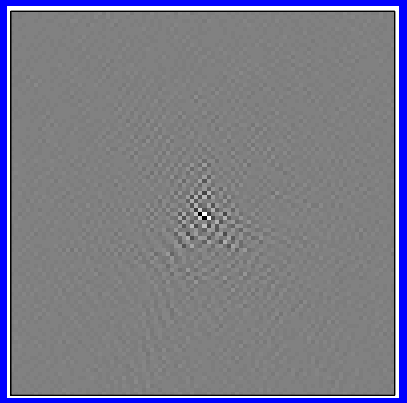
Wednesday, May 11, 2005

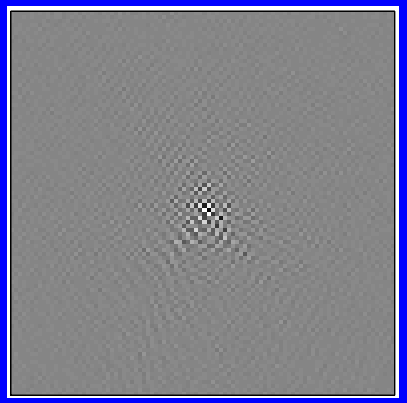
ISMRM 13^{th} Scientific Meeting and Exhibition

Background

- Reconstruction
  - Real and Imaginary $\Rightarrow$ Magnitude and Phase



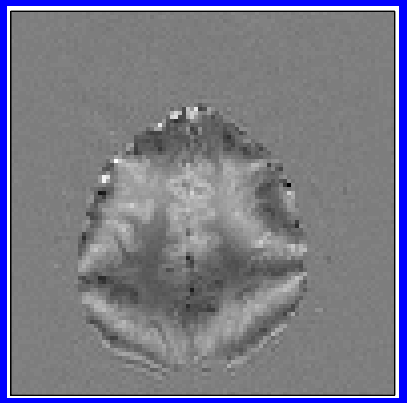
(a) Real K-space



(b) Imaginary K-space

Background

- Reconstruction
  - Real and Imaginary $\Rightarrow$ Magnitude and Phase

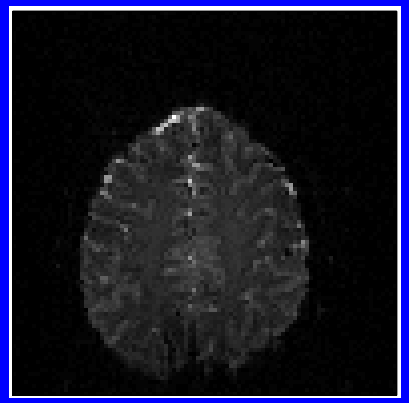


(c) Real Image

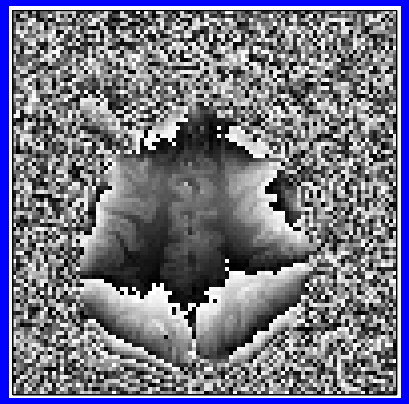
(d) Imagninary Image

Background

- Reconstruction
  - Real and Imaginary $\Rightarrow$ Magnitude and Phase



(e) Magnitude Image



(f) Phase Image

Bandettini et al. MRM 30:161-173(1993). Cox et al. MRM 33:230-236(1995).

Background

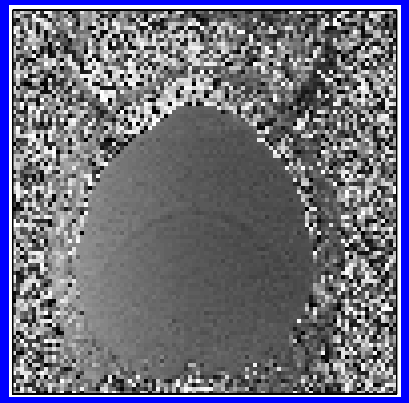
- Reconstruction
  - Real and Imaginary $\Rightarrow$ Magnitude and Phase
- The BOLD Signal
  - Physiological and physical sources of magnitude and phase changes

- CBF
- CBV
- $CMRO_2$
- IV/EV Origin
- Venous Size
- Venous Orientation

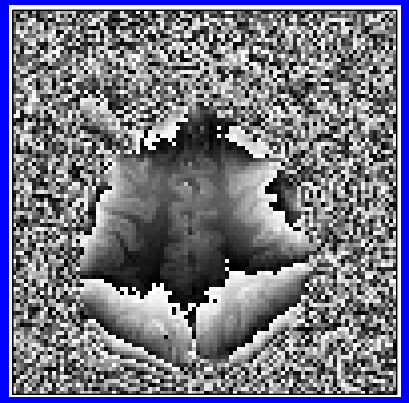
Ogawa et al. Biophys. Journ. 64:803-812(1993). Duong et al. MRM 49:1019-1027(2003). Menon MRM 47:1-9(2002).

Background

- Reconstruction
  - Real and Imaginary $\Rightarrow$ Magnitude and Phase
- The BOLD Signal
  - Physiological and physical sources of magnitude and phase changes
- Spin Echo (SE) and Gradient Recalled Echo (GE) Pulse Sequences
  - SE removal of constant dephasing



(g) SE Phase



(h) GE Phase

Jochimsen et al. MRM 52:724-732(2004)

Activation Calculations

- Magnitude Activations
  - Disregard phase information
  - Assume normal noise on the magnitude data

$$M = X\beta + \epsilon, \qquad \epsilon \sim N(0, \sigma^2 I)$$

$$M = \begin{pmatrix} m_1 \\ \vdots \\ m_i \end{pmatrix}, X = \begin{pmatrix} 1 & 1 & \pm 1 \\ \vdots & \vdots & \vdots \\ 1 & i & \pm 1 \end{pmatrix}, \beta = \begin{pmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \end{pmatrix}$$

Rowe NeuroImage 25:1310-1324(2005). Bandettini et al. MRM 30:161-173(1993). Cox et al. MRM 33:230-236(1995). Rowe, Logan NeuroImage 24:603-606(2005)

Activation Calculations

- Magnitude Activations
  - Disregard phase information
  - Assume normal noise on the magnitude data

$$M = X\beta + \epsilon, \qquad \epsilon \sim N(0, \sigma^2 I)$$

- Magnitude Activations in Complex Data Assuming Constant Phase
  - Assume constant phase based upon physics
  - Assume normal noise in the complex data

$$\begin{pmatrix} R \\ I \end{pmatrix} = \begin{pmatrix} X & 0 \\ 0 & X \end{pmatrix} \begin{pmatrix} \beta\cos\theta \\ \beta\sin\theta \end{pmatrix} + \eta, \qquad \eta \sim N(0, \sigma^2 I)$$

Rowe NeuroImage 25:1310-1324(2005).

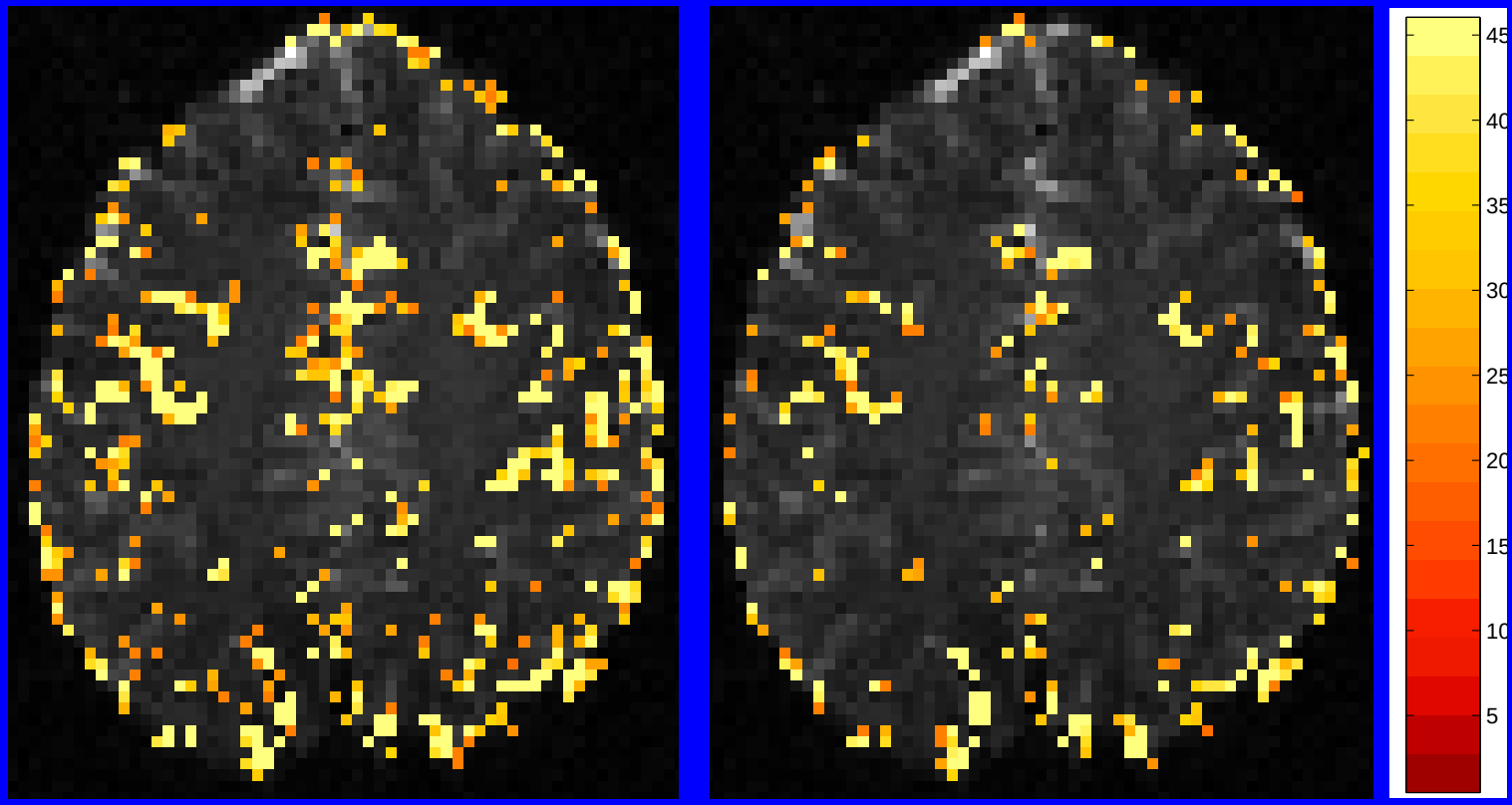
Rowe, Logan NeuroImage 23:1078-1092(2004).

Methods

- Task
  - Bilateral finger tapping–20s off; 20 sets of 16s on, 16s off
  - Performed during SE scan and immediately afterwards in GE scan
- Scanning
  - Parameters identical for the two scans for comparison purposes
- Activations (voxels above threshold)
  - Determined for a single slice through the motor cortex
  - First 3 time points omitted
  - Ideal 0/1 Fourier filter of low frequency and respiratory noise
  - $\alpha = .05$, Bonferroni adjusted

Logan, Rowe NeuroImage 22:95-108(2004).

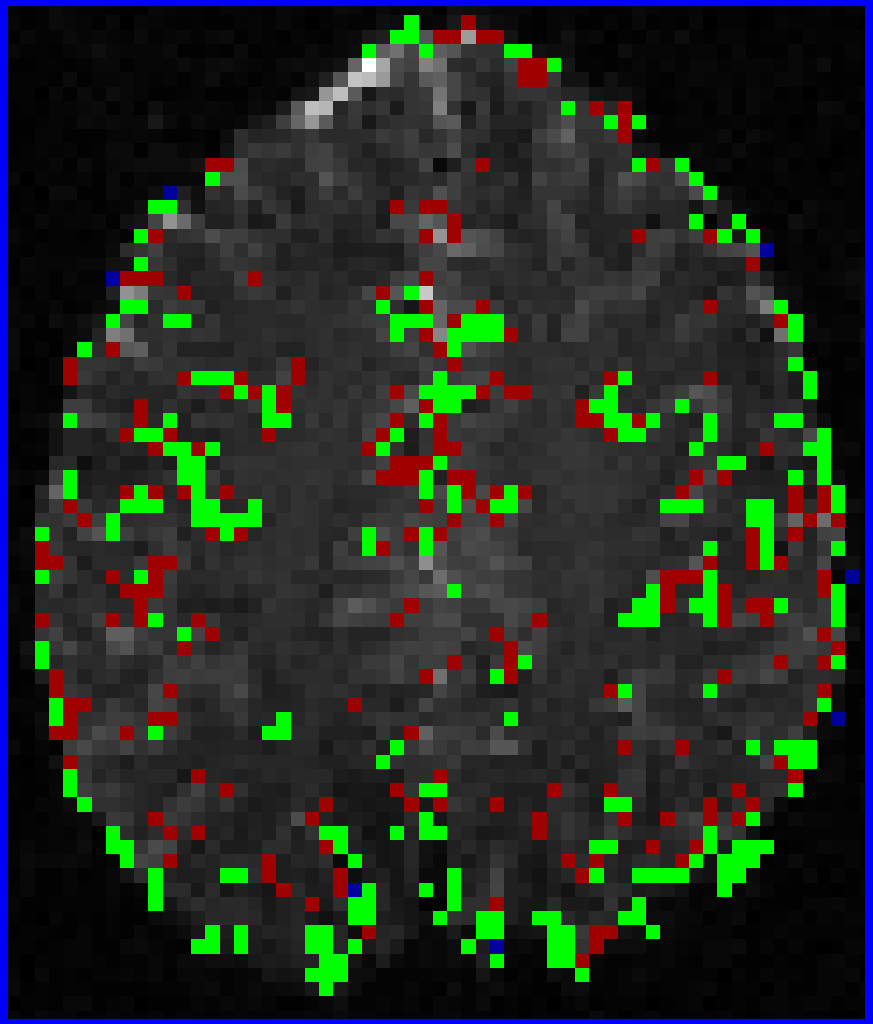
GE: χ^2 Statistics Above Threshold



(i) Magnitude

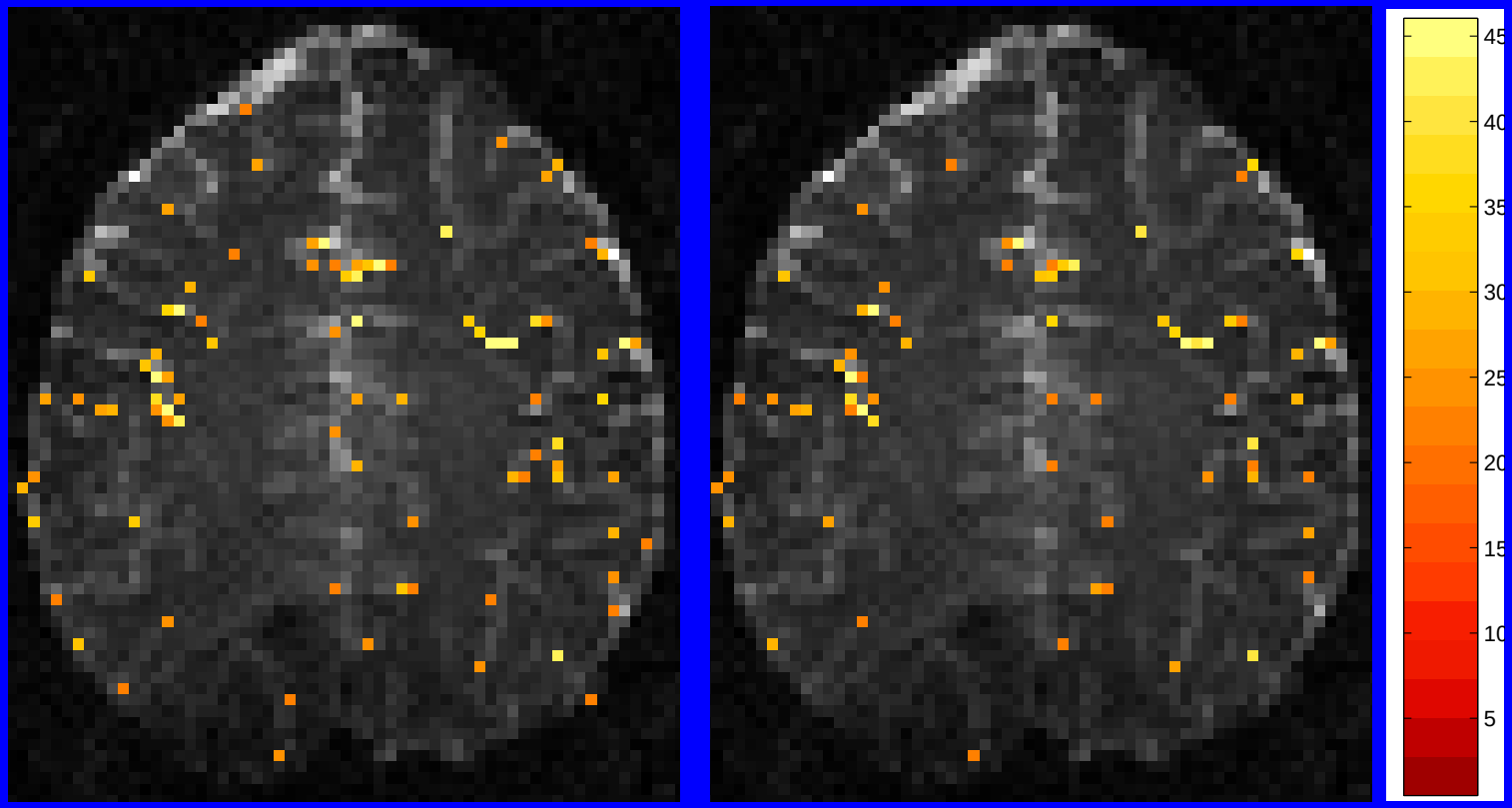
(j) Complex Constant Phase

GE: χ^2 Statistics Above Threshold



- Red: Magnitude Only
- Blue: Complex Constant Phase Only
- Green: Both

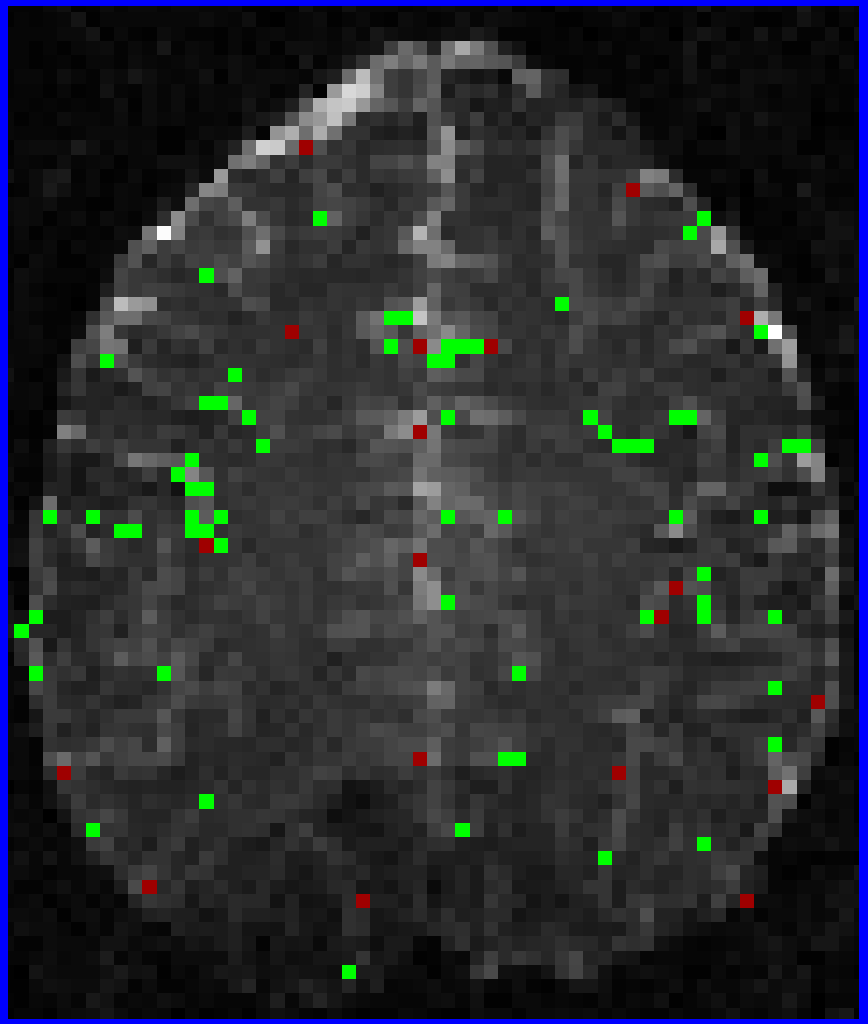
SE: χ^2 Statistics Above Threshold



(k) Magnitude

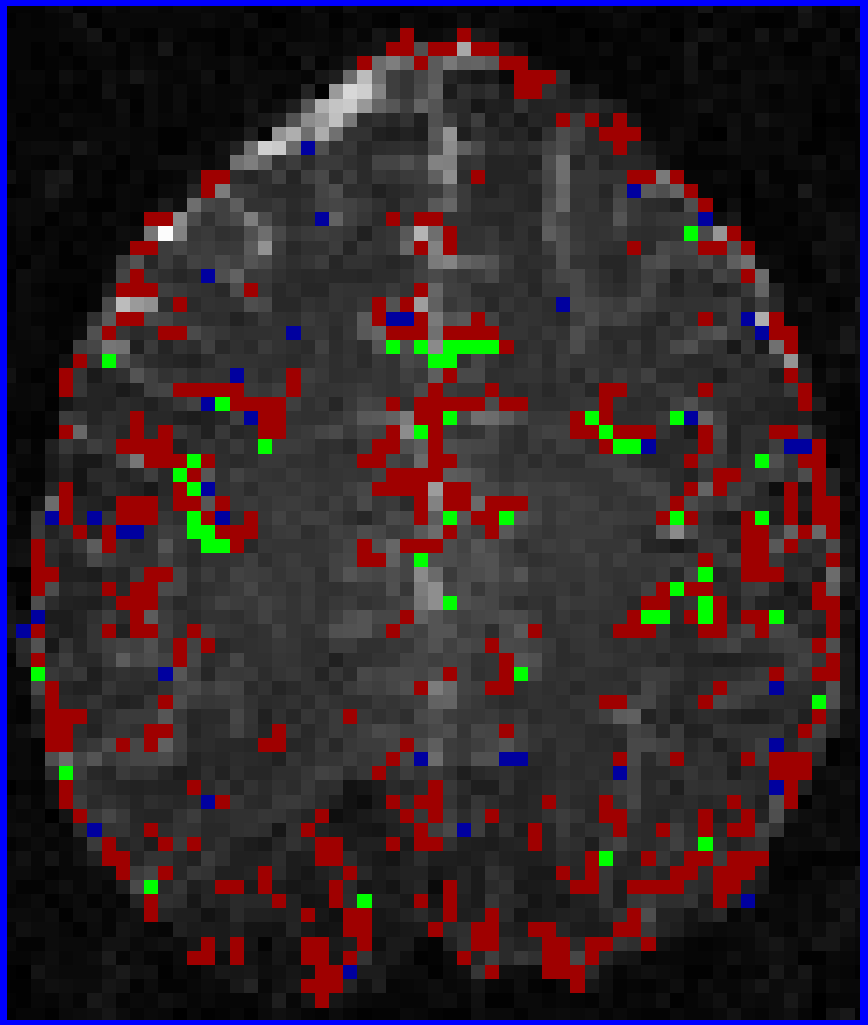
(l) Complex Constant Phase

SE: χ^2 Statistics Above Threshold



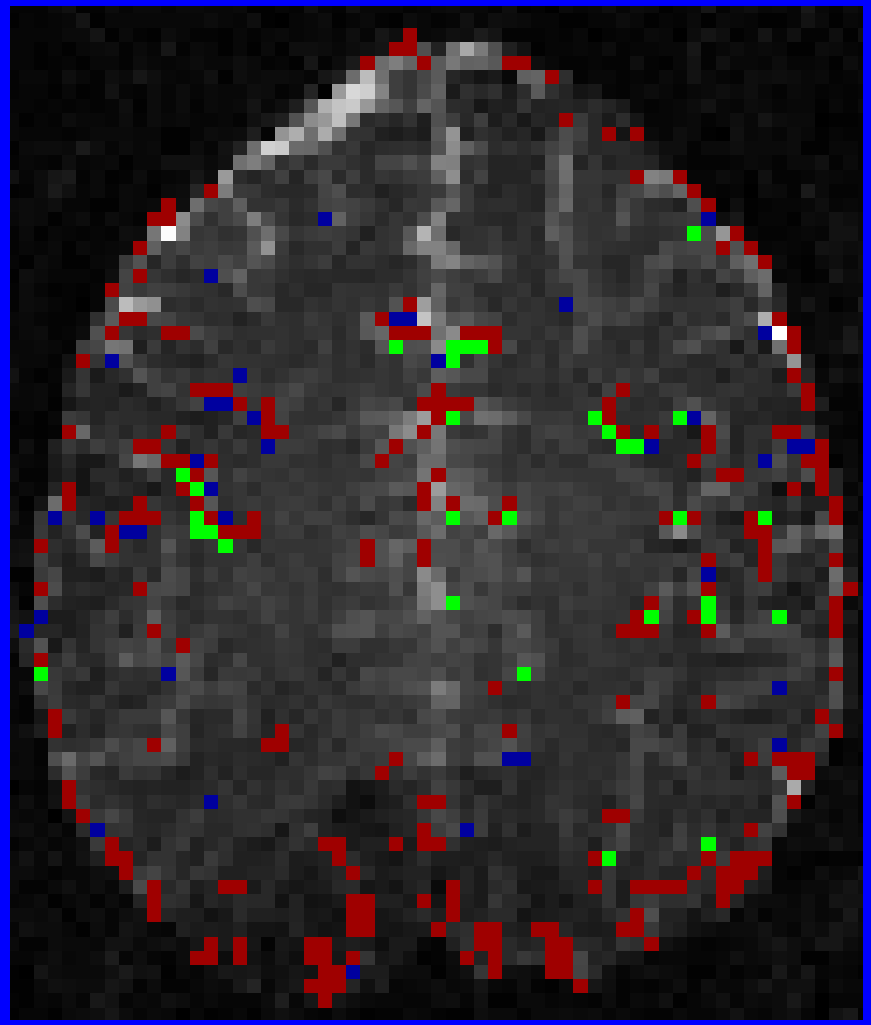
- Red: Magnitude Only
- Blue: Complex Constant Phase Only
- Green: Both

Magnitude Activations



- Red:
  GE Only
- Blue:
  SE Only
- Green:
  Both

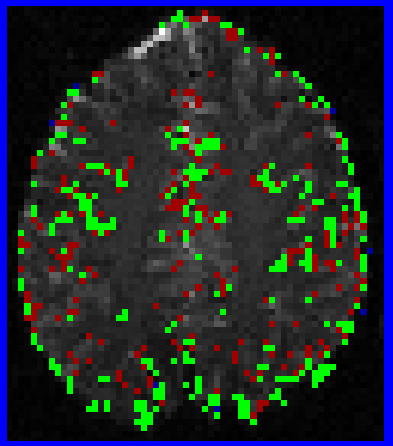
Complex Constant Phase Activations



- Red:
  GE Only
- Blue:
  SE Only
- Green:
  Both

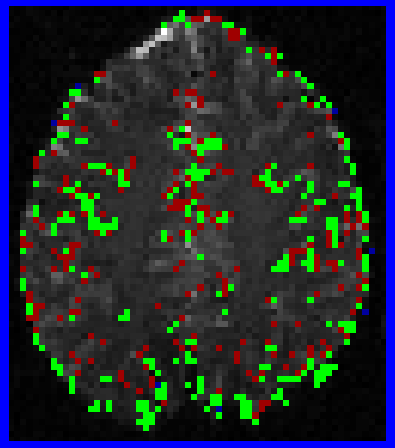
Conclusions

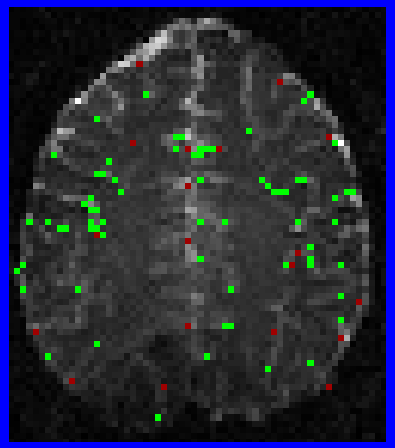
- GE Acquisition
  - Complex constant phase activations are a subset of the magnitude activations
  - Complex constant phase method biases against draining vein contributions



Conclusions

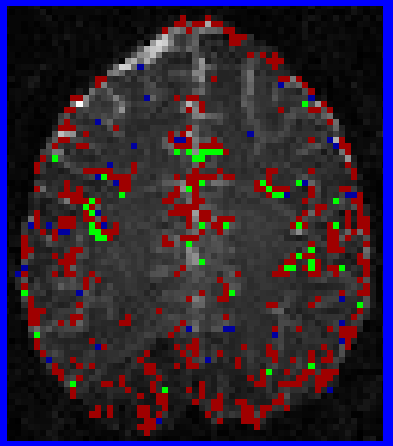
- GE Acquisition
  - Complex constant phase activations are a subset of the magnitude activations
  - Complex constant phase method biases against draining vein contributions
- SE Acquisition
  - Complex constant phase activations nearly identical to magnitude activations
  - Complex constant phase method only biases against draining veins





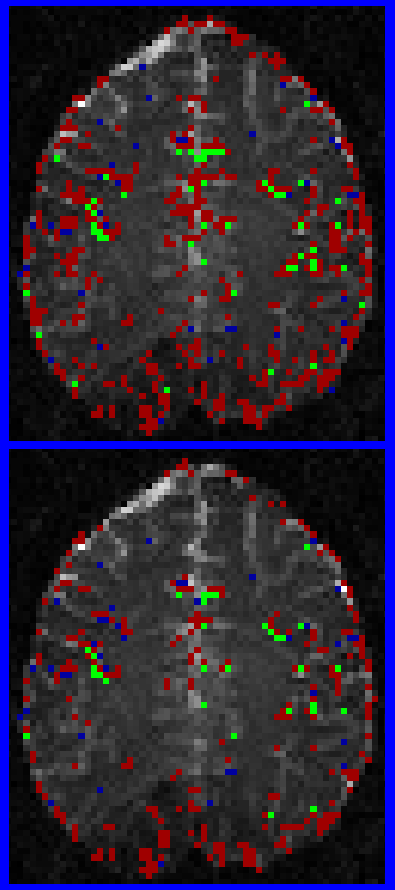
Conclusions

- SE and GE Pulse Sequences
  - Magnitude
    - SE activations are a subset of GE
    - SE removes venous component



Conclusions

- SE and GE Pulse Sequences
  - Magnitude
    - SE activations are a subset of GE
    - SE removes venous component
  - Complex Constant Phase
    - SE activations remain a subset of GE
    - SE removes venous component which was not biased against by the complex constant phase method

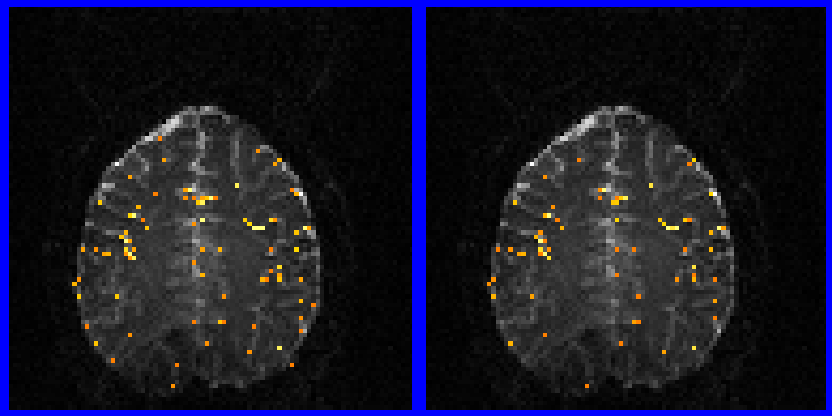


Thank You

Thank you for your attention.

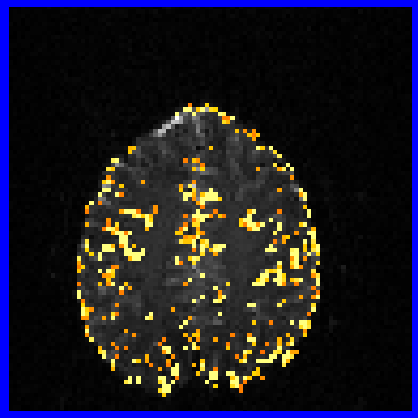
- Funding
  - NIH R01EB00215

Full Activation Maps

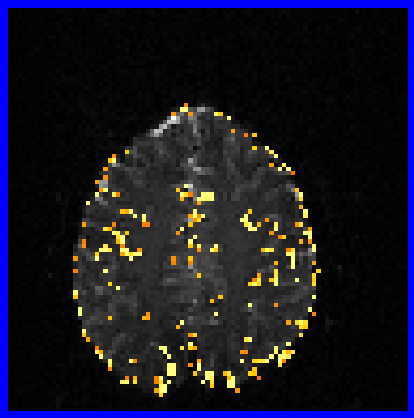


(m) SE Magnitude

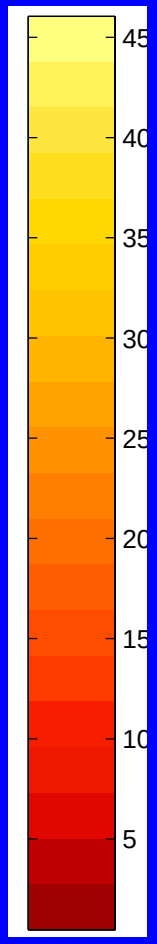
(n) SE CCP



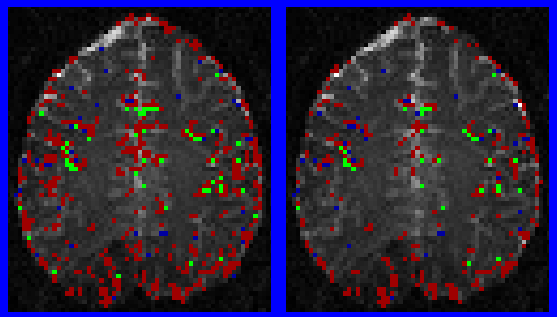
(o) GE Magnitude



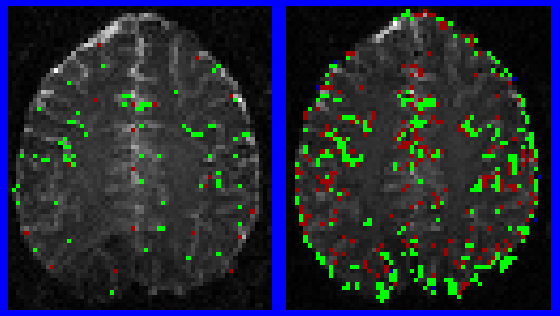
(p) GE CCP



Overlay Maps



(q) M: SE & GE (r) CP: SE & GE

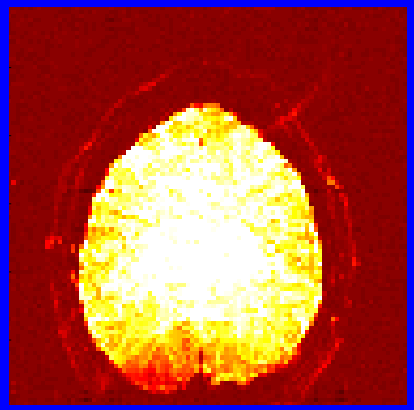


(s) SE: M & CP (t) GE: M & CP

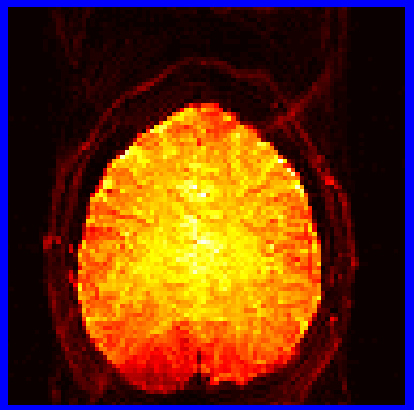
	Only SE	Only GE	Both
Magnitude	39	462	49
Constant Phase	38	256	31

	Only Magnitude	Only Constant Phase	Both
SE	19	0	69
GE	231	7	280

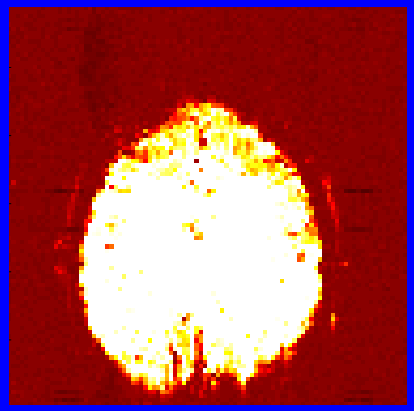
SNR Maps



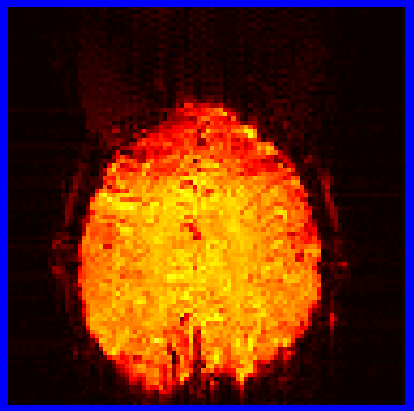
(u) SE Magnitude SNR



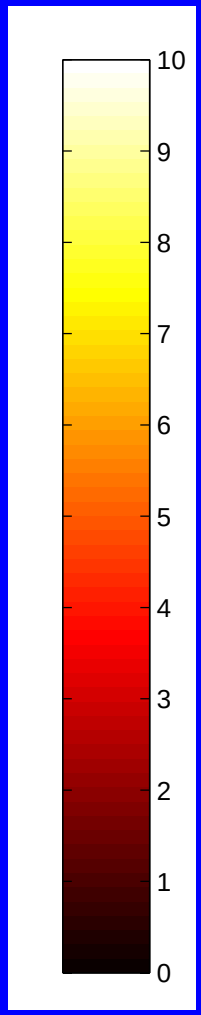
(v) SE CCP SNR



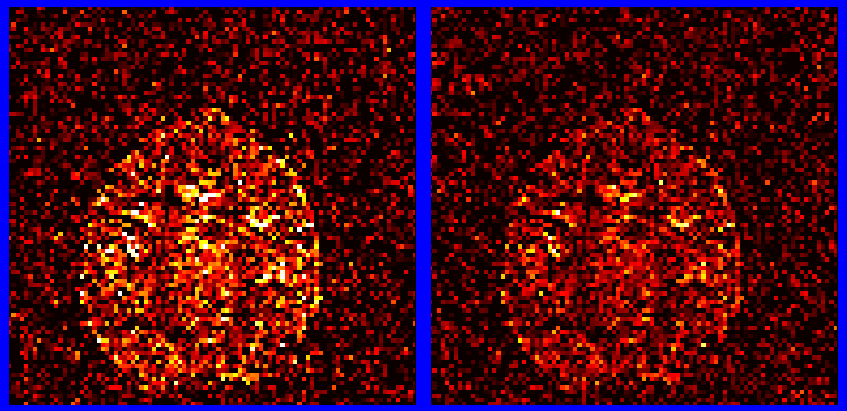
(w) GE Magnitude SNR



(x) GE CCP SNR

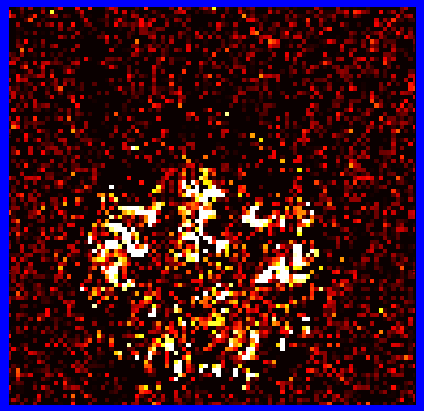


CNR Maps

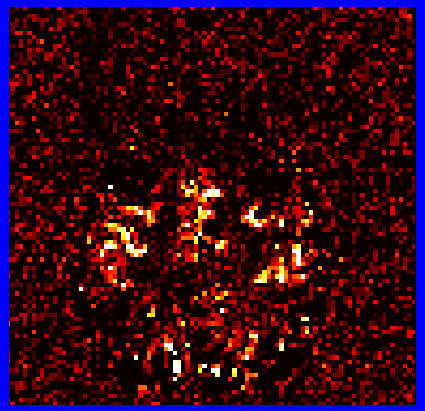


(y) SE Magnitude CNR

(z) SE CCP CNR



() GE Magnitude CNR



() GE CCP CNR