Modeling Resting Cerebral Perfusion from BOLD Signal Dynamics During Hyperoxia

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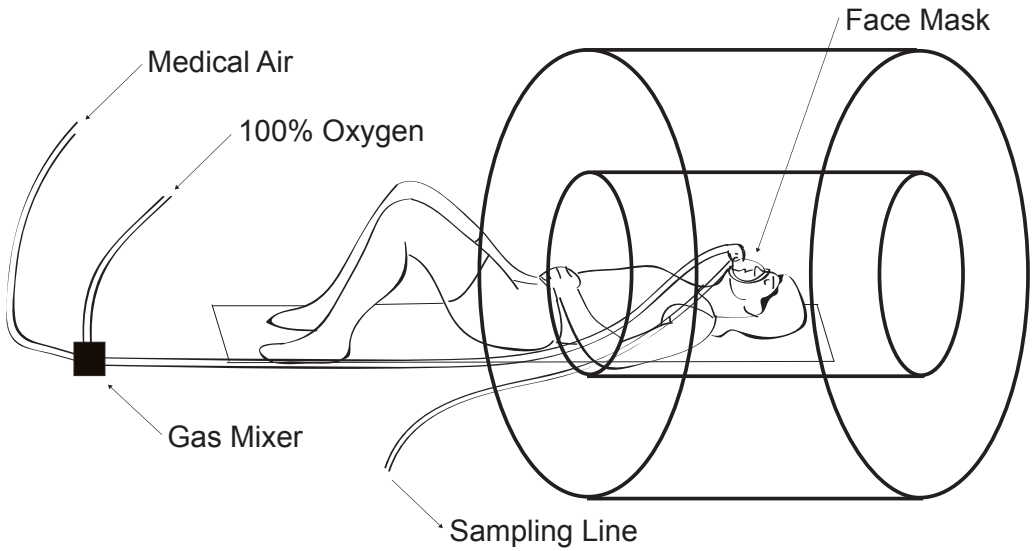
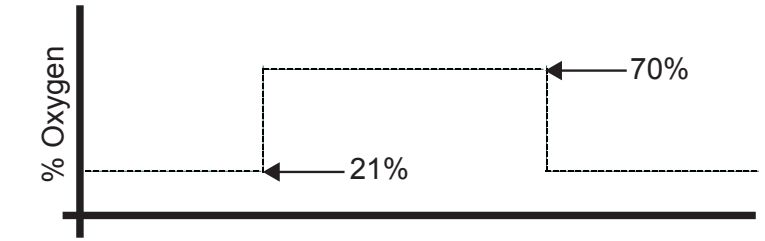
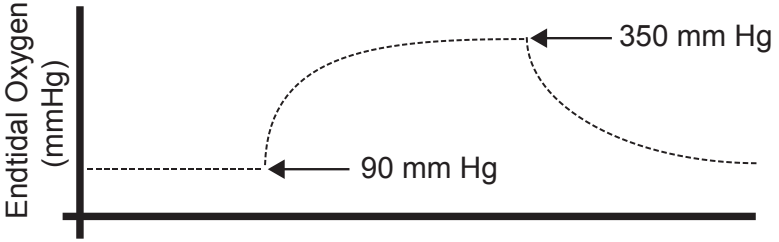
Introduction

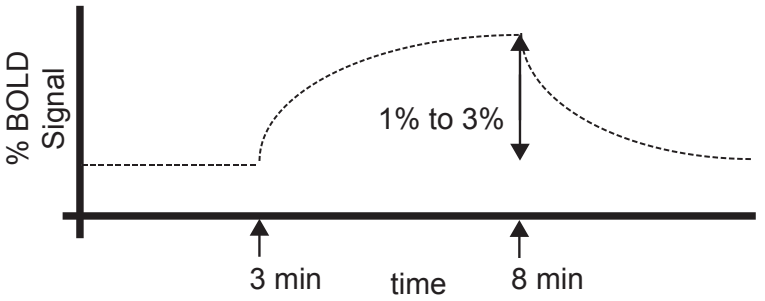
- Perfusion parameters: CBV, CBF, and MTT can be calculated with different techniques
- Additional inhaled oxygen changes the concentration of deoxygenated hemoglobin and the signal intensity of blood oxygen level dependent (BOLD) MRI
- This work proposes a new method for obtaining perfusion parameters by the modeling the dynamic passage of oxygen

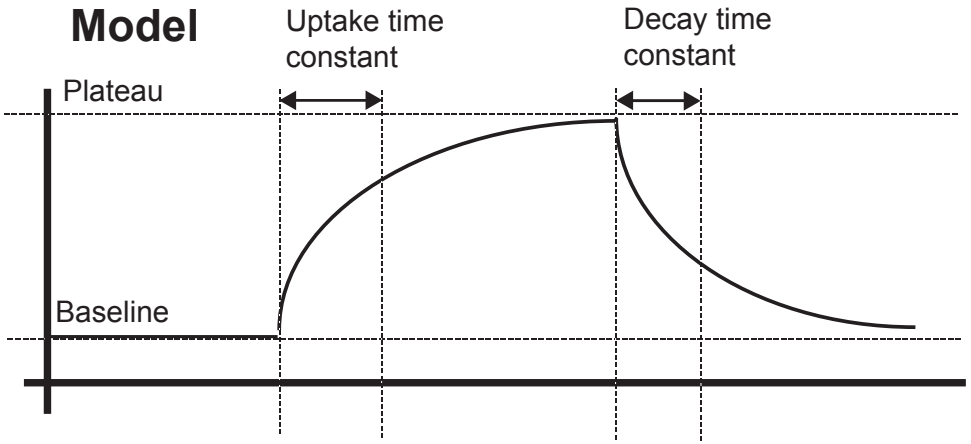
Experimental Paradigm







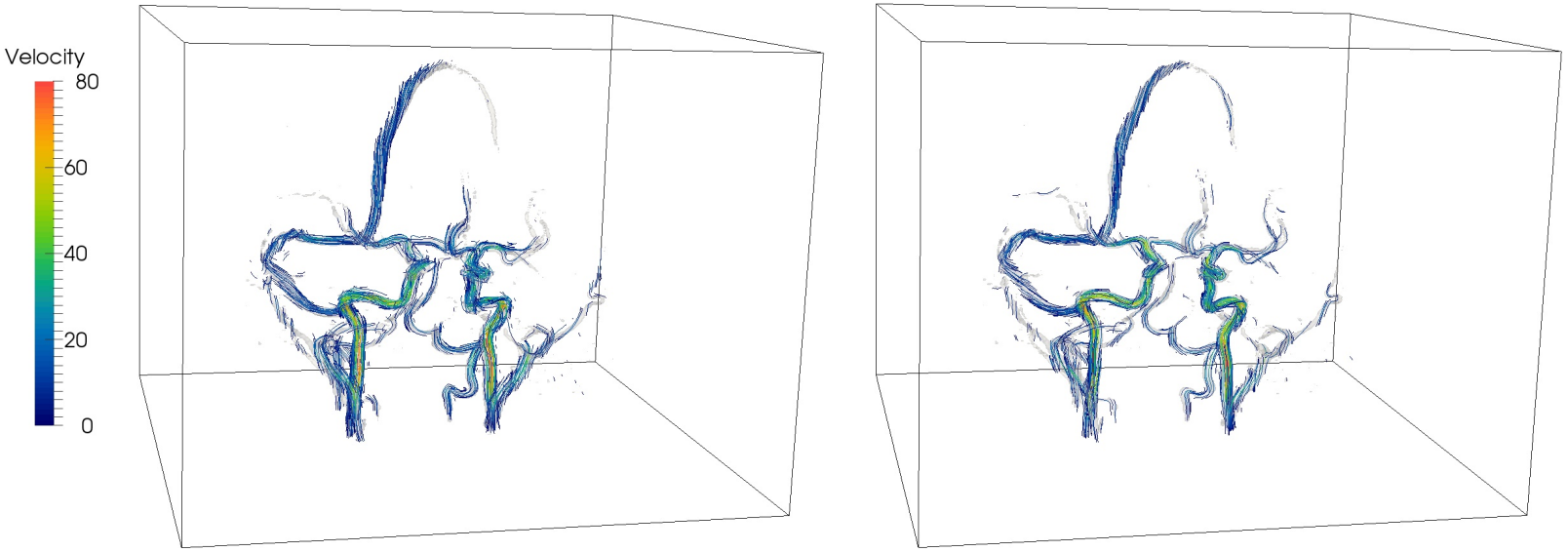


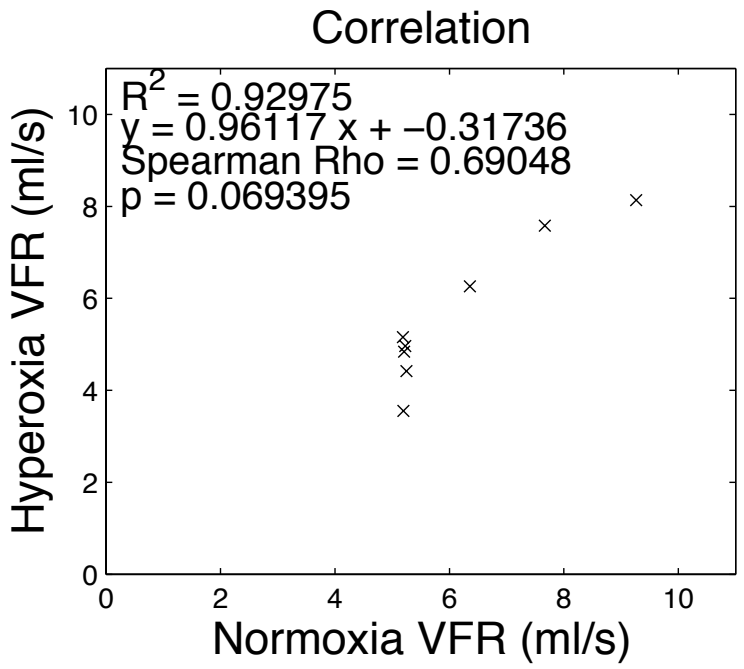


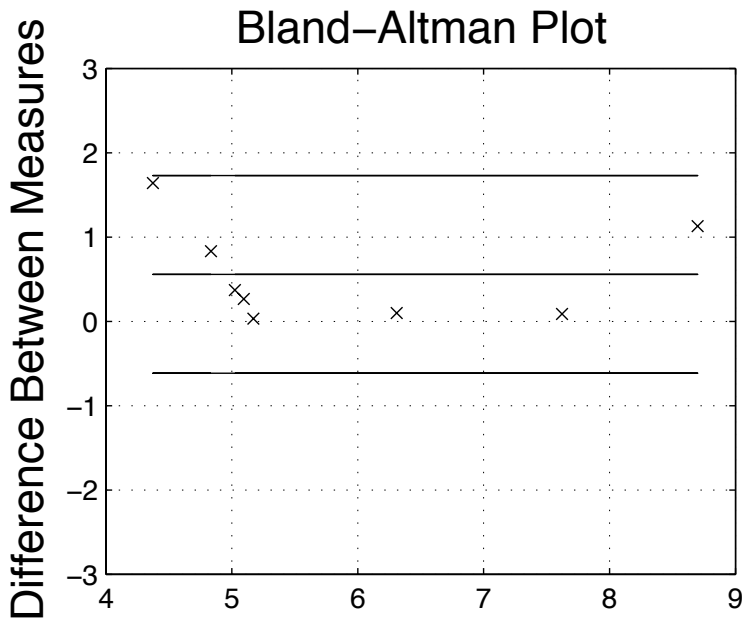
Methods – assert O_2's effect on CBF

- One subject was imaged with phase contrast velocity mapping under normoxia and hyperoxia (inhaling 70% oxygen)
- Flow volume was measured at several segments for Bland Altman analysis
- Three subjects were imaged with arterial spin labeling, with and without hyperoxic stimulus (Correction for T1 of blood)
- Difference images in the CBF maps were calculated

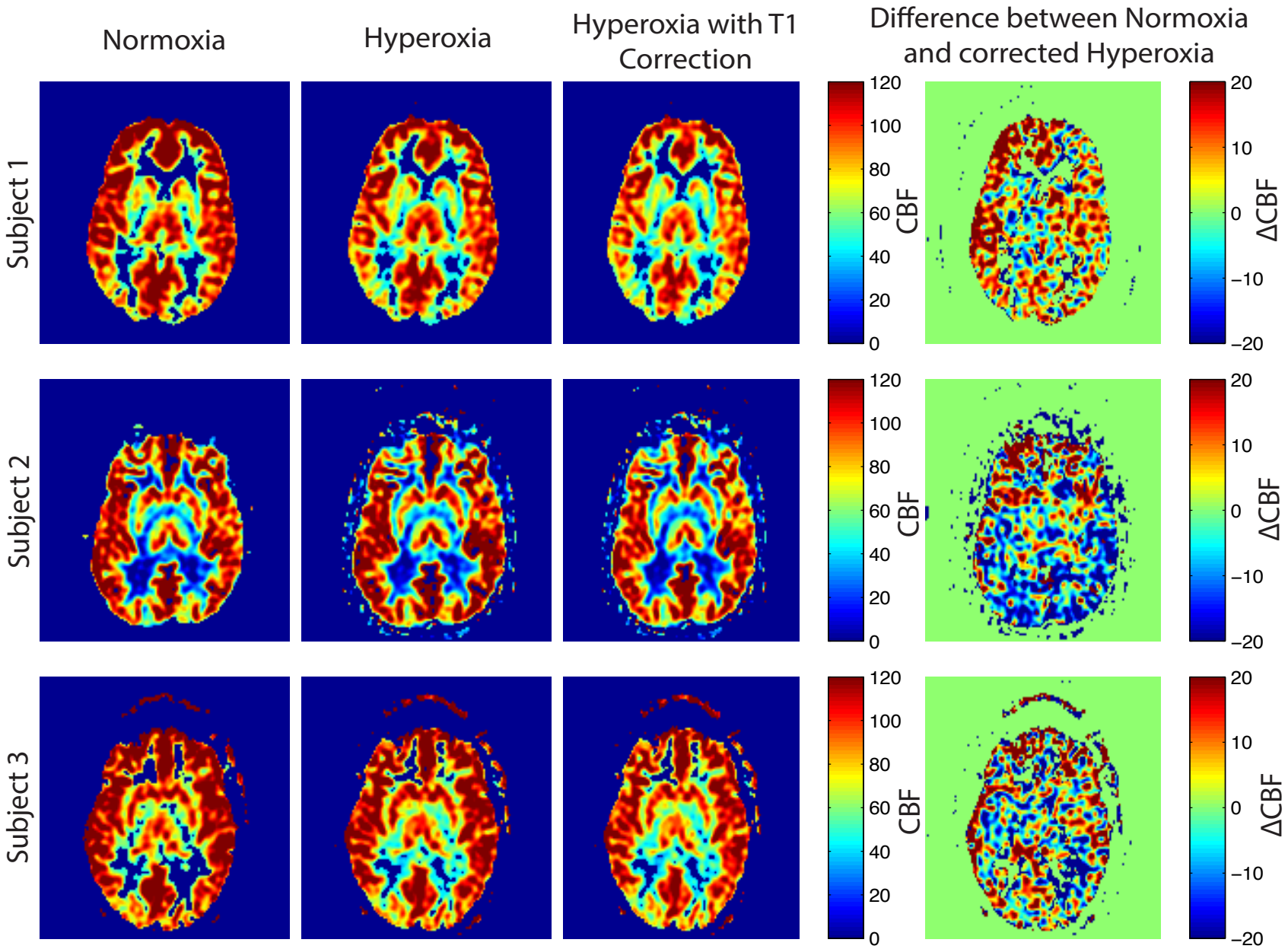
Results – Phase Contrast







Results – Arterial Spin Labeling



Theory

$$\delta S_t \approx \mathrm{TE}\ \mathrm{CBV_V}\ \Delta[\mathrm{Hb}]$$

$$\mathrm{CBV_V} = \left(\frac{\mathrm{A}}{\mathrm{TE}} + \mathrm{B}\right)\left(\frac{\mathrm{C}}{\Delta \mathrm{PaO_2}} + \mathrm{D}\right)\delta S_t$$

$$\mathrm{C_a} = \phi[\mathrm{Hb}]\mathrm{Sa_{O2}} + \epsilon \mathrm{Pa_{O2}}$$

$$\mathrm{Sa_{O2}} = \frac{1}{\left(\frac{23400}{(\mathrm{Pa_{O2}})^2 + 150(\mathrm{Pa_{O2}})} + 1\right)}$$

$$\mathrm{C_t\,(t)} = \mathrm{k_2}\ \mathrm{TE}\ \left(\frac{\mathrm{S_{T2^*}\,(t)} - \mathrm{S_{T2^*}}|_0}{\mathrm{S_{T2^*}}|_0}\right)^{\beta}$$

$$\mathrm{C_t\,(t)} = \mathrm{CBF}\ \mathrm{C_a\,(t)} \otimes \mathrm{R\,(t)}$$

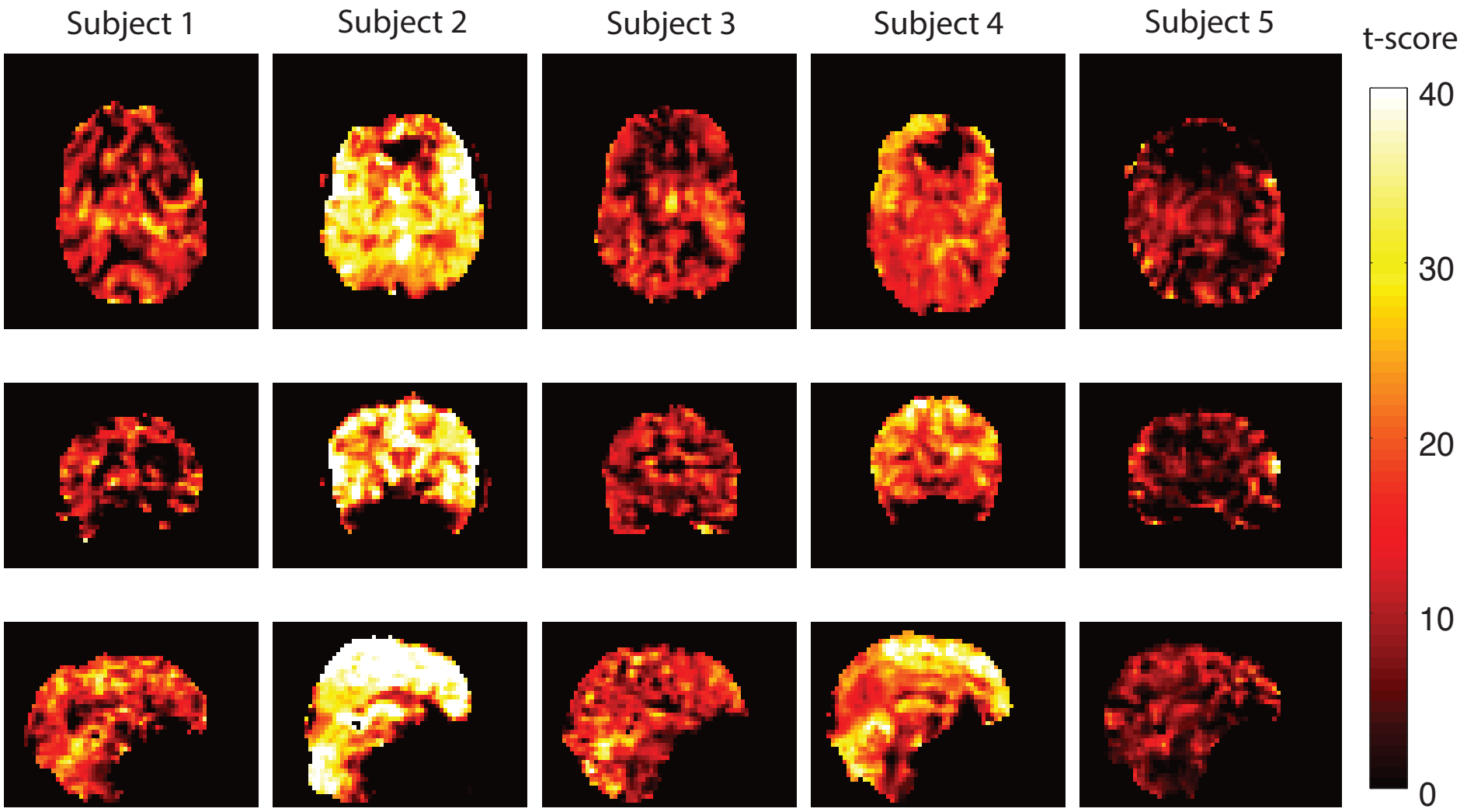
Methods

- Images acquired on a GE Discover 750 with a 12 channel head coil
- Five subjects were imaged with a BOLD imaging protocol:
  - EPI - TR/TE/flip of 2000 ms/30 ms/80°
  - 64 x 64 x 43
    over 224 mm x 224 mm 150.5 mm
  - 390 volumes in 13 minutes
- 3-5-5 minute paradigm
  normoxia - hyperoxia (70%) - normoxia

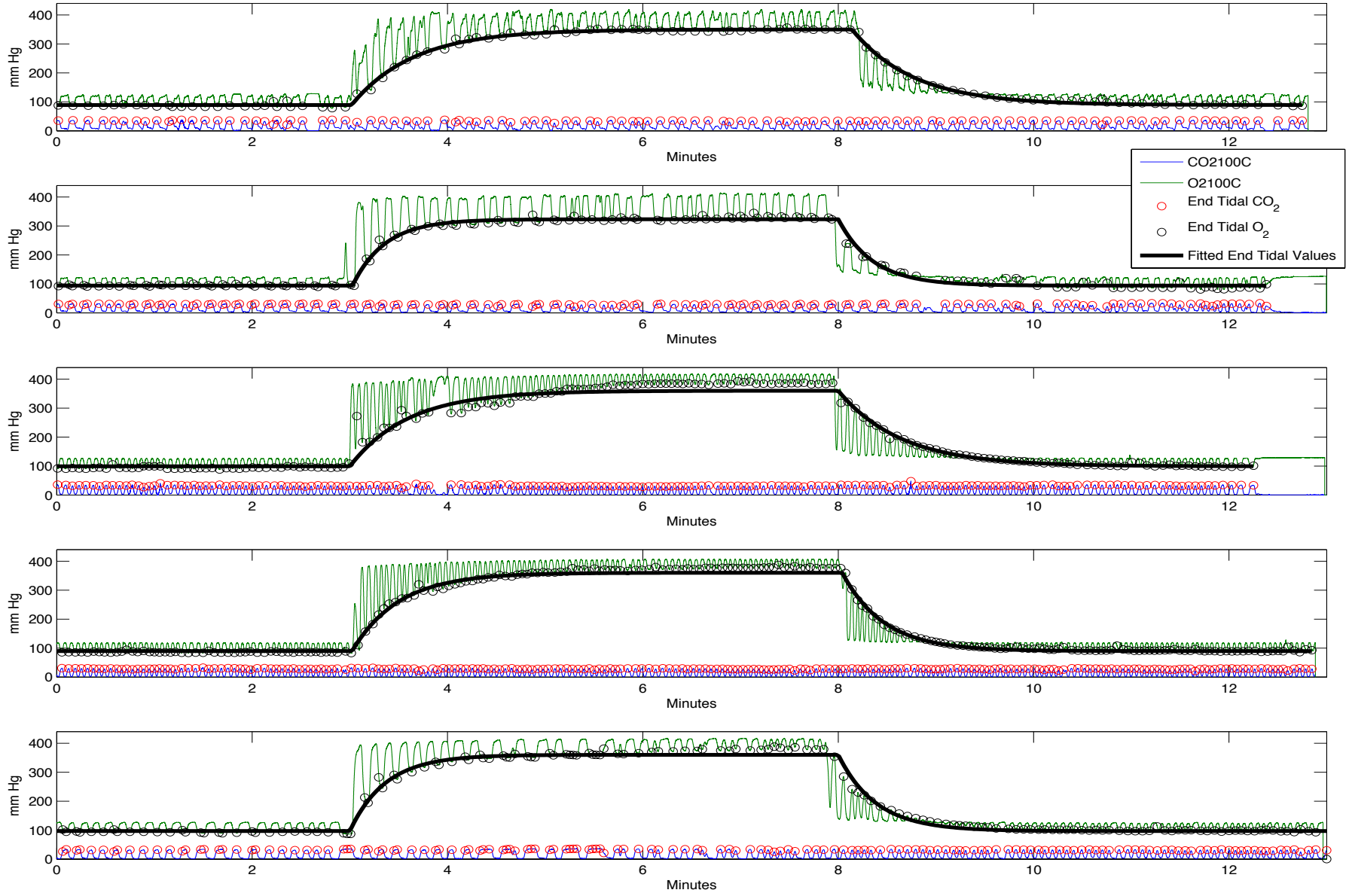
Methods

- **Post processing:**
  - **motion correction, spatial smoothing**
- **Calculated t-stat maps using a fixed gamma PDF response (FWHM 60 seconds)**
- **Implemented the model and calculated perfusion parameters**
- **Performed deconvolution operation with spectral division**
- **Performed model fitting with a conjugate gradient lease squares implementation**

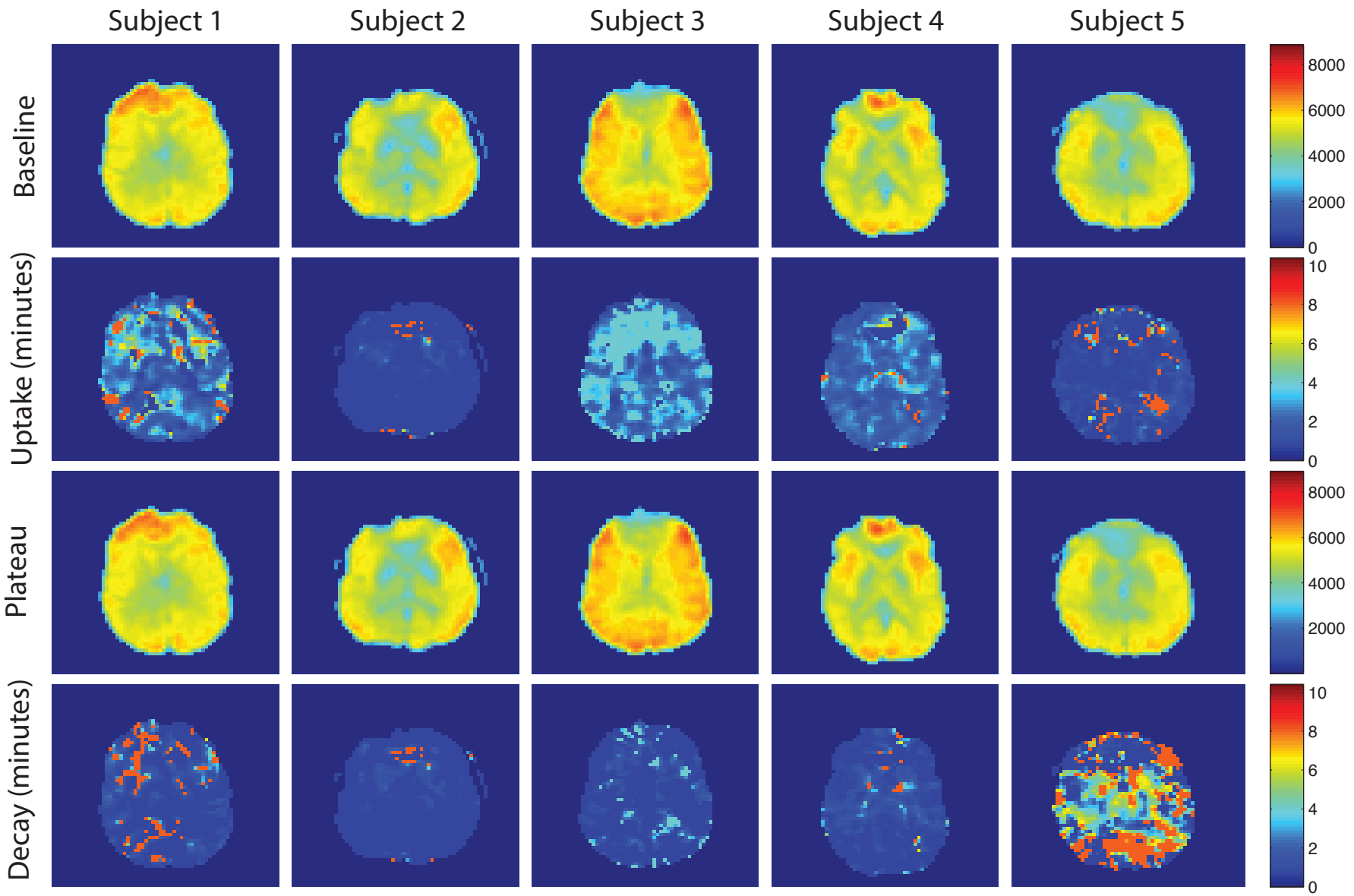
Results – Statistical Maps



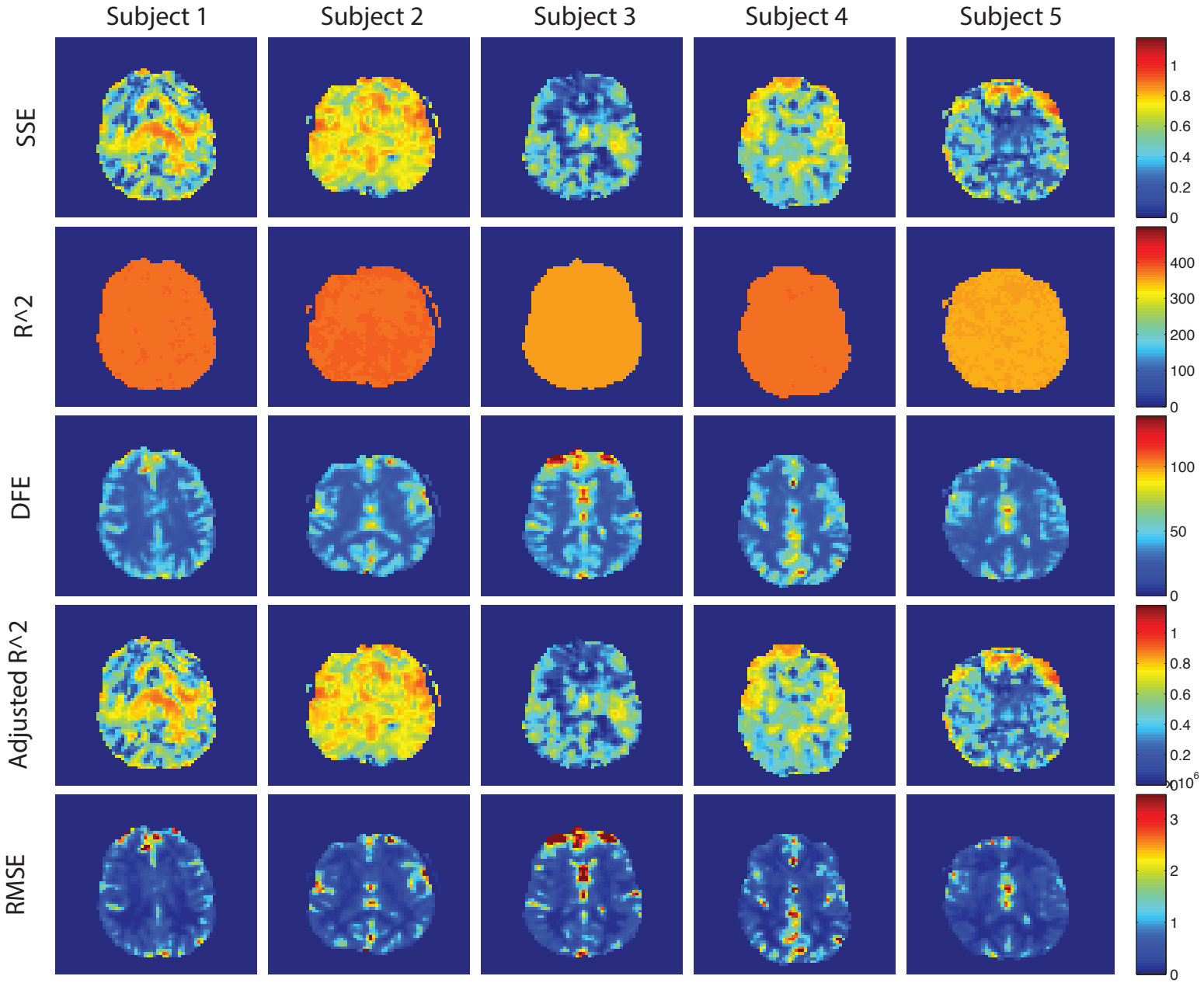
Results – End-tidal Values



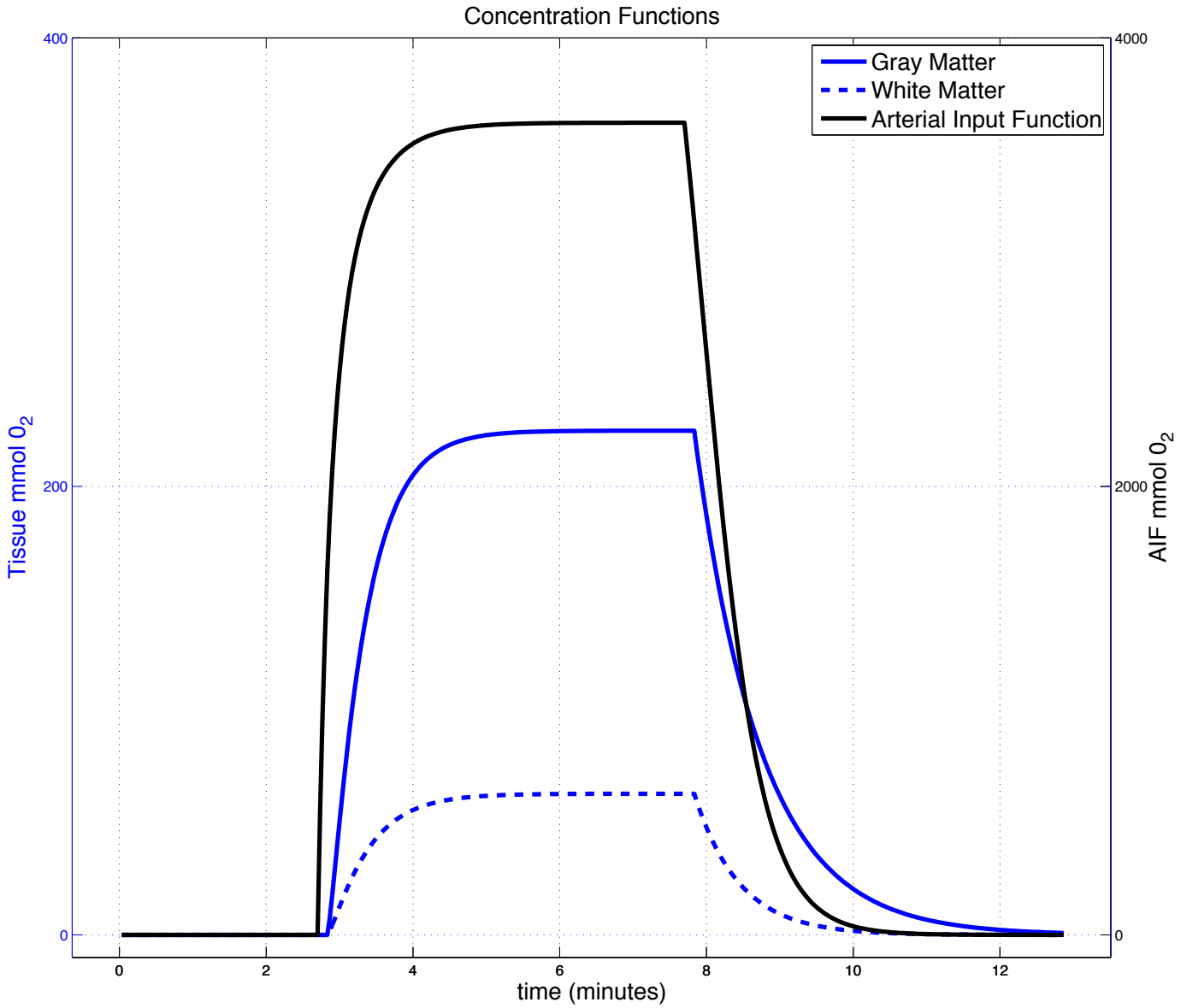
Results – Parameters



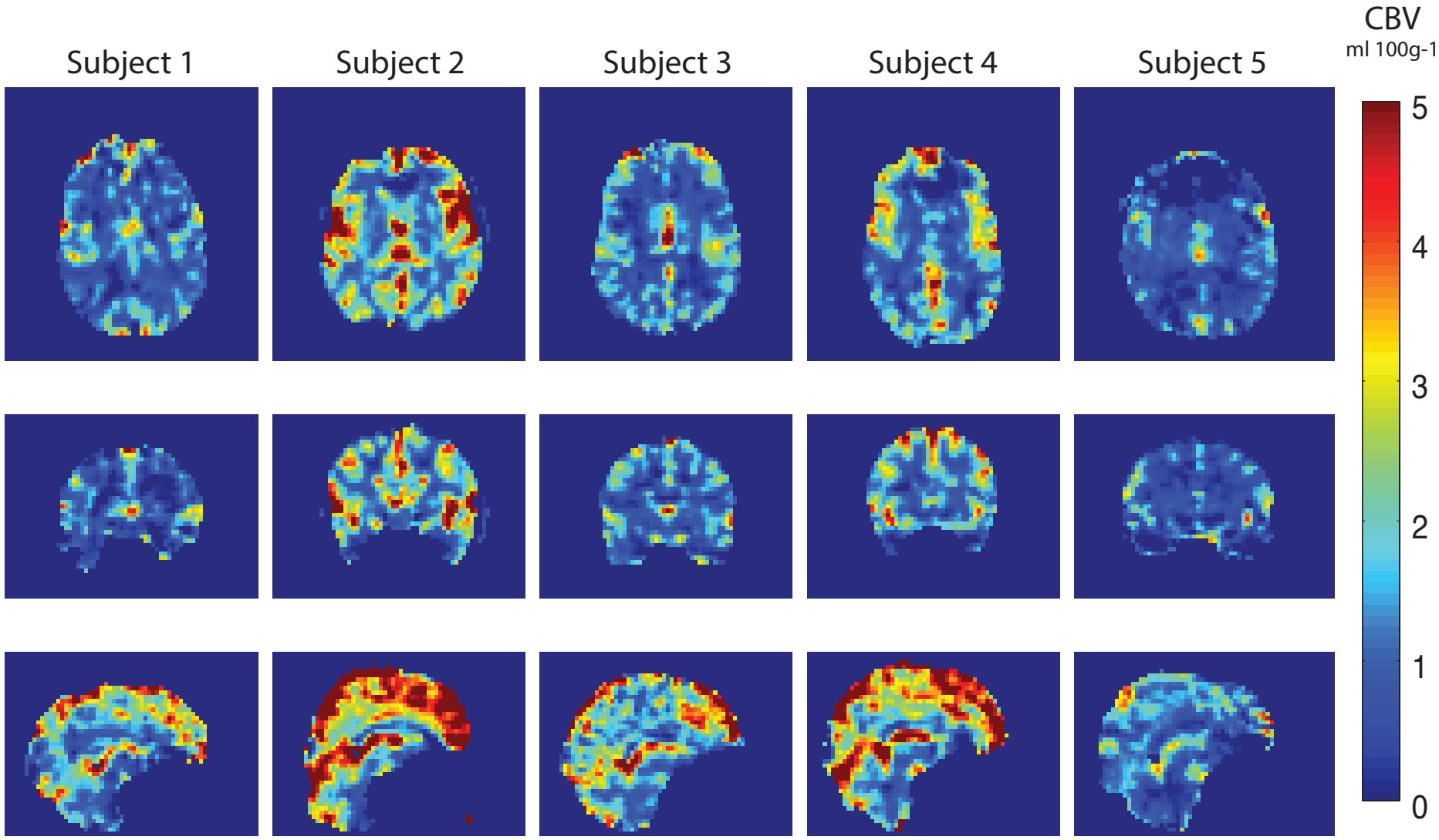
Results – Goodness of Fit



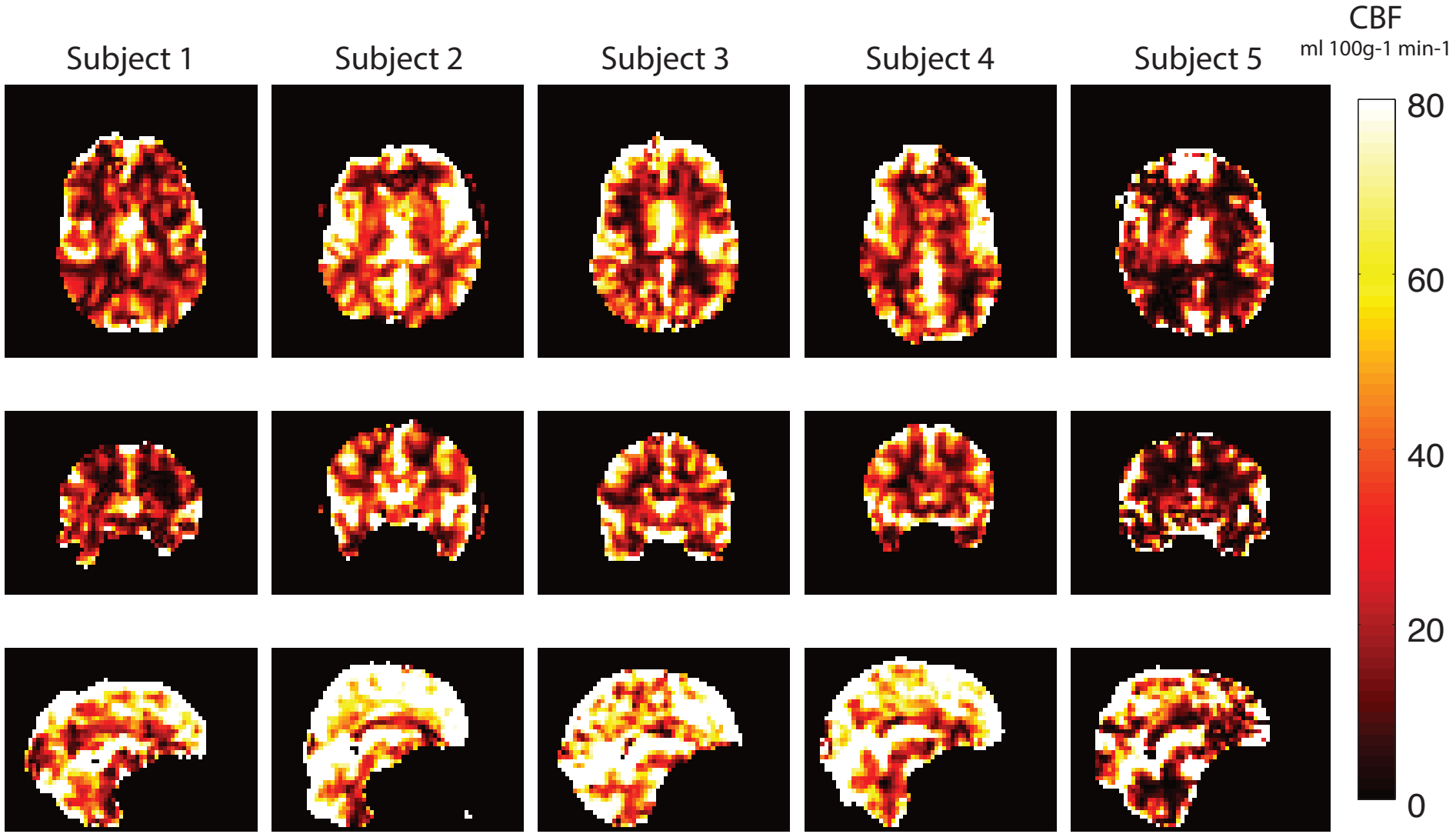
Results – Concentration Functions



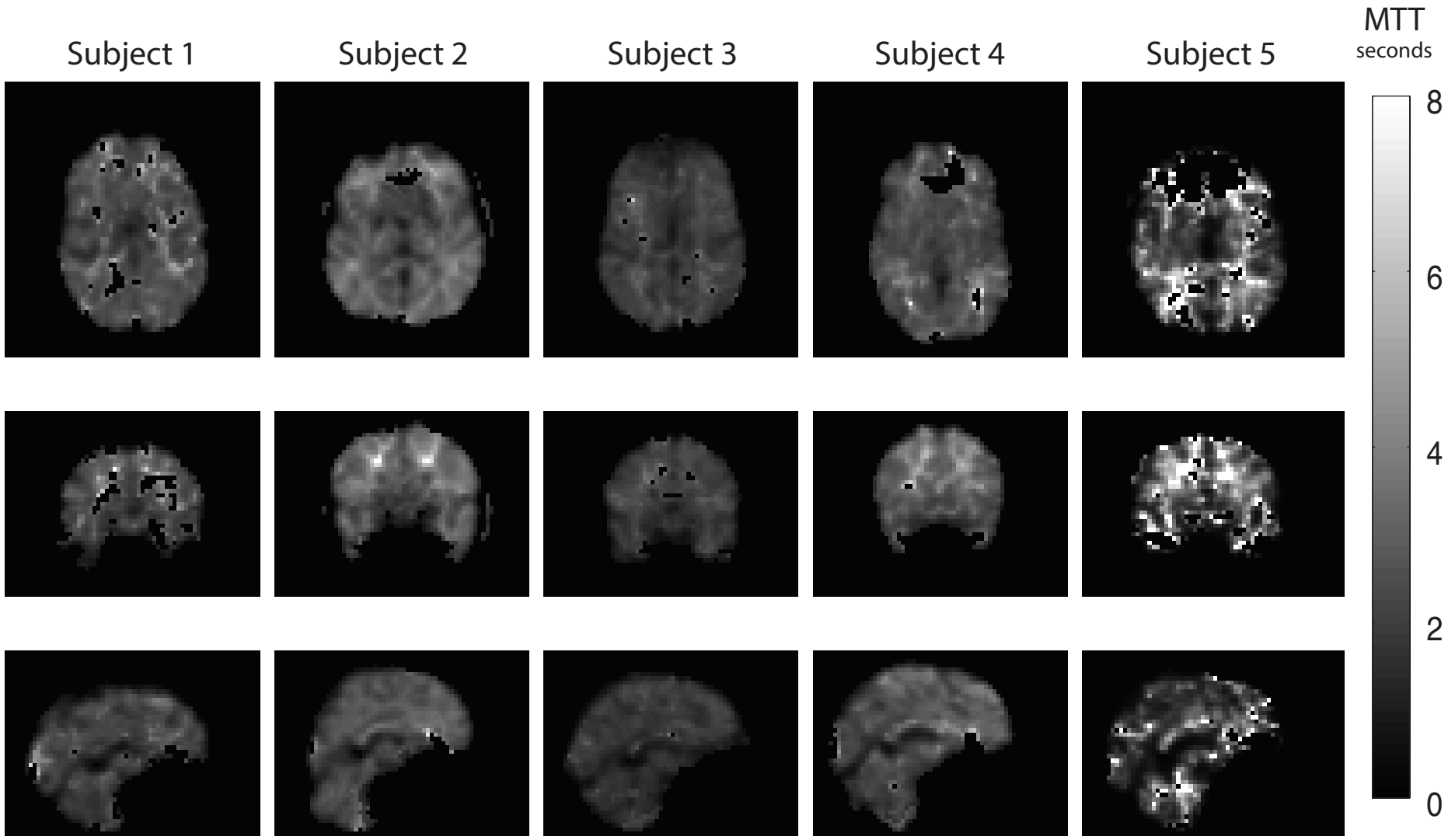
Results – Cerebral Blood Volume (CBV)



Results – Cerebral Blood Flow (CBF)



Results – Mean Transit Time (MTT)



Results – GM and WM Measurements

	CBF (ml 100g-1 min-1)		CBV (ml 100g-1)		MTT (seconds)	
	GM	**WM**	**GM**	**WM**	**GM**	**WM**
Subject 1	61.2	26.5	1.57	0.93	2.05	2.73
Subject 2	64.4	24.1	1.07	0.78	2.54	3.91
Subject 3	82.2	34.4	1.84	1.11	1.64	2.12
Subject 4	59.7	27.2	1.97	1.25	2.48	3.39
Subject 5	86.1	30.1	2.79	1.46	2.53	3.47
Average	**70.7**	**28.5**	**1.85**	**1.11**	**2.25**	**3.12**

Discussion – Part 1

- Phase contrast and arterial spin labeling asserted no significant change in CBF during this hyperoxia stimulus
- Shorter repeated blocks (like in the abstract) were found to be undesirable as the slow hyperoxia stimulus took longer to plateau
- No problems with partial volume effects as the arterial function is derived from the end-tidal measurements

Discussion – Part 2

- This method demonstrates a new contrast mechanism for obtaining perfusion parameters
- Very slow uptake allows for more images unlike gadolinium passage
- Perfusion parameters are weighted towards the venous circulation
- No injection required, and still able to detect to longer delayed times (unlike ASL)

References

1. Ogawa S, Lee T-M, Nayak AS, Glynn P. Oxygenation-sensitive contrast in magnetic resonance image of rodent brain at high magnetic fields. Magn Reson Med 1990;14(1):68-78.

2. Buxton RB. Introduction to Functional Magnetic Resonance Imaging: Principles and Techniques: Cambridge University Press; 2009.

3. Tofts PS. Modeling tracer kinetics in dynamic Gd-DTPA MR imaging. J Magn Reson Imaging 1997;7(1):91-101.

4. Calamante F, Gadian DG, Connelly A. Delay and dispersion effects in dynamic susceptibility contrast MRI: Simulations using singular value decomposition. Magn Reson Med 2000;44(3): 466-473.

5. Buckley DL. Uncertainty in the analysis of tracer kinetics using dynamic contrast-enhanced T1-weighted MRI. Magn Reson Med 2002;47(3):601-606.

6. MacDonald ME, Frayne R. Cerebrovascular MRI: a review of state-of-the-art approaches, methods and techniques. NMR Biomed 2015;28(7):767-791.

7. Severinghaus JW. Simple, accurate equations for human blood O2 dissociation computations. J Appl Physiol 1979;46(3):599-602.

8. Cui W, Zhu X-H, Vollmers ML, Colonna ET, Adriany G, Tramm B, Dubinsky JM, Oz G. Non-invasive measurement of cerebral oxygen metabolism in the mouse brain by ultra-high field 17O MR spectroscopy. J Cereb Blood Flow Metab 2013;33(12):1846-1849.

9. Haddock B, Larsson HBW, Hansen AE, Rostrup E. Measurement of brain oxygenation changes using dynamic T1-weighted imaging. Neuroimage 2013;78(0):7-15. 12. Bulte DP, Chiarelli PA, Wise RG, Jezzard P. Cerebral perfusion response to hyperoxia. J Cereb Blood Flow Metab 2006;27(1):69-75.

10. Blockley NP, Griffeth VEM, Germuska MA, Bulte DP, Buxton RB. An analysis of the use of hyperoxia for measuring venous cerebral blood volume: Comparison of the existing method with a new analysis approach. Neuroimage 2013;72(0):33-40.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