What influences the fMRI signal?

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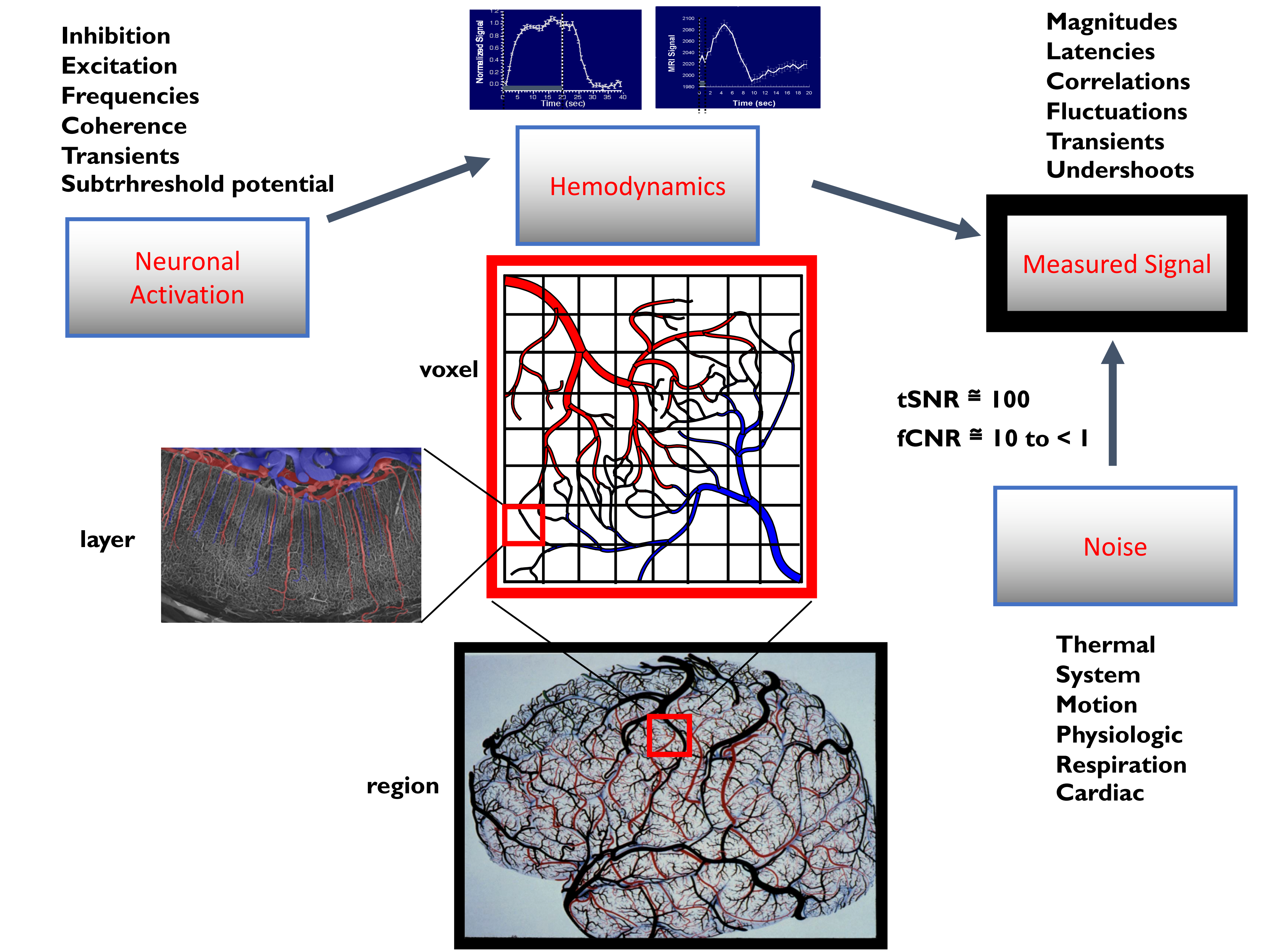
DEPARTMENT OF HEALTH & HUMAN SERVICES · USA

NATIONAL INSTITUTES OF HEALTH

NIMH National Institute of Mental Health

LABORATORY OF LBC BRAIN AND COGNITION

FIM fim.nimh.nih.gov


Inhibition
Excitation
Frequencies
Coherence
Transients
Subtrhreshold potential
Neuronal Activation
Normalized Signal
Time (sec)
MRI Signal
Time (sec)
Hemodynamics
Magnitudes
Latencies
Correlations
Fluctuations
Transients
Undershoots
Measured Signal
voxel
tSNR ≅ 100
fCNR ≅ 10 to < 1
layer
Noise
region
Thermal
System
Motion
Physiologic
Respiration
Cardiac

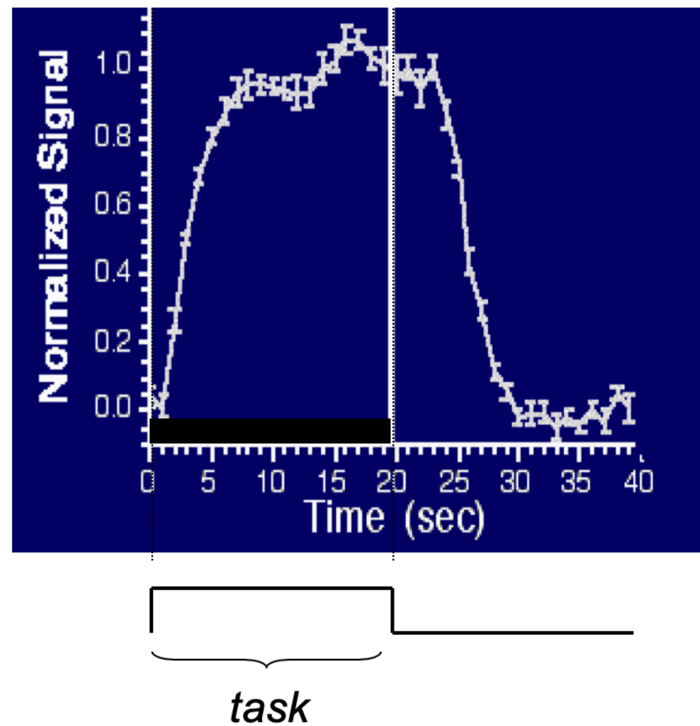
What Measures Can we Obtain with fMRI and MRI?

fMRI Signal: (BOLD, volume, perfusion):

- Location
- Extent
- Magnitude
- Width or shape
- Latency
- Post undershoot
- Transients within activation response
  (pre undershoot, initial transient, post transient, post undershoot)
- Changes in activation over time/repeats/task intensity...
- Multi-voxel pattern
- Connectivity
- Mutual information
- Decode-ability
- Resting state: resting state correlation magnitude and extent
- Resting state: dynamics of resting state (i.e. windowed correlation)
- Resting state: Spatial or temporal components
  (overall latency, pulsatility, entropy, information, etc..)
- BOLD/flow ratio -> CMRO2
- SE/GE ratio -> vessel geometry

- **Anatomy:**

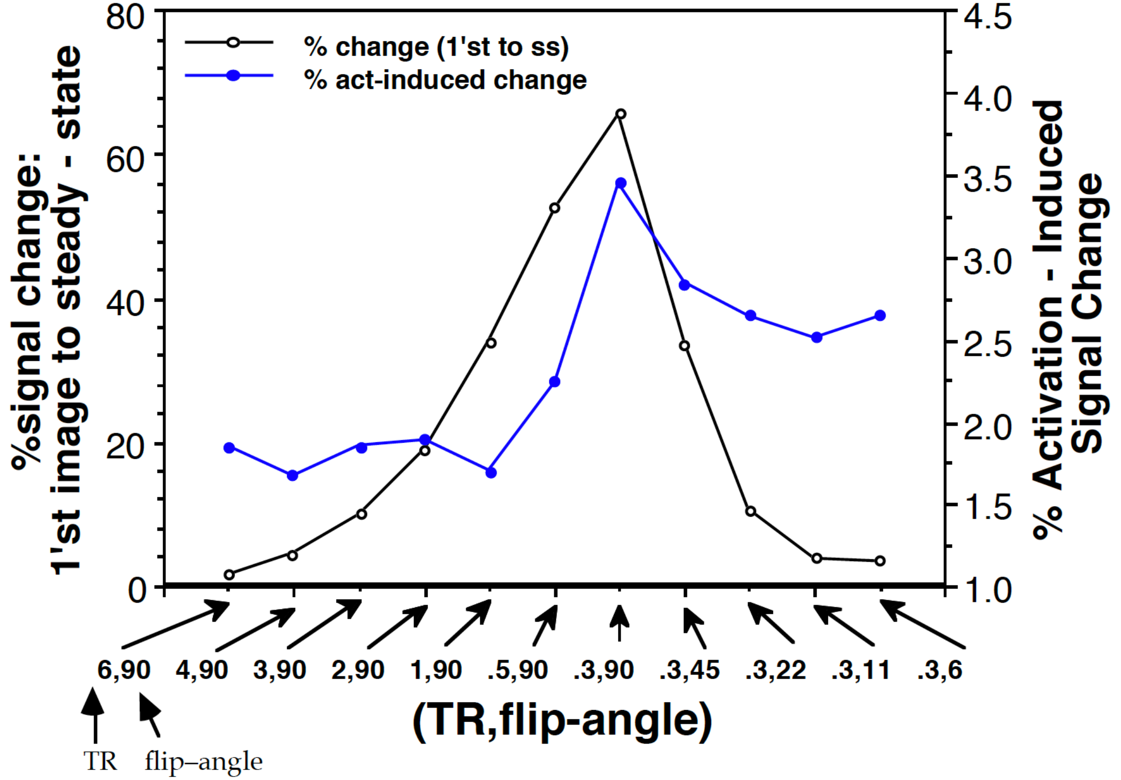
- White matter
- Gray matter density & volume
- CSF
- Mylenation
- Gyrification
- Fractal Dimension
- Fractional anisotropy
- Susceptibility weighted measurements (blood volume and iron)
- Magnetization transfer, spin-locking, etc...



What Physical Parameters Influence the fMRI signal?

- TR: inflow, tissue signal
- TE: BOLD, IV signal
- Field Strength
- Flip Angle
- Diffusion weighting
- MT: macromolecules
- Slice Thickness
- Voxel Dimension
- Readout Direction

TR



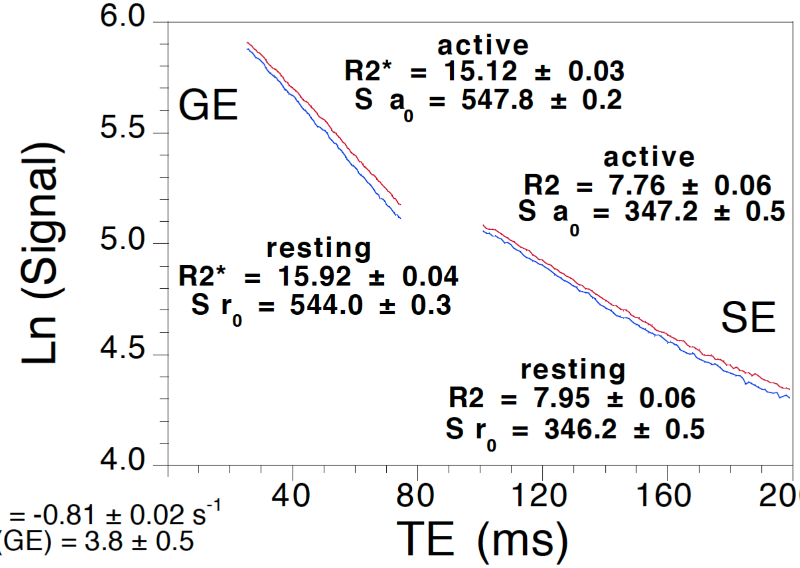
80
60
40
20
0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
% change (1'st to ss)
% act-induced change
%signal change:
1'st image to steady - state
% Activation - Induced
Signal Change
6,90
4,90
3,90
2,90
1,90
.5,90
.3,90
.3,45
.3,22
.3,11
.3,6
(TR,flip-angle)
TR
flip–angle

TR

Shorter TR:

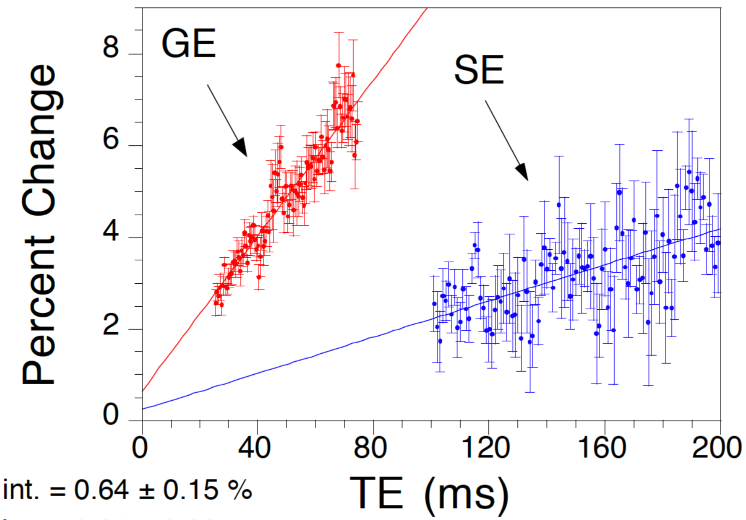
- **Increases samples per unit time**
- **Increases inflow effects on outer slices**
- **Decreases SNR**
- **Allows physiologic fluctuations to be better characterized and remove.**

TE

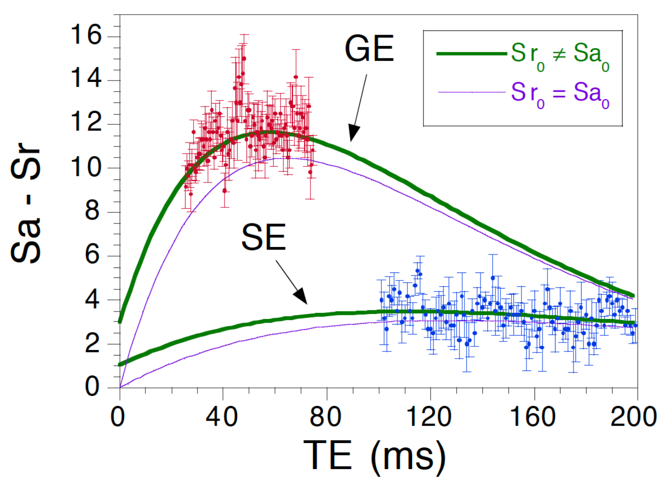


$\Delta R2^* = -0.81 \pm 0.02\ s^{-1}$
ΔS_0 (GE) = 3.8 ± 0.5

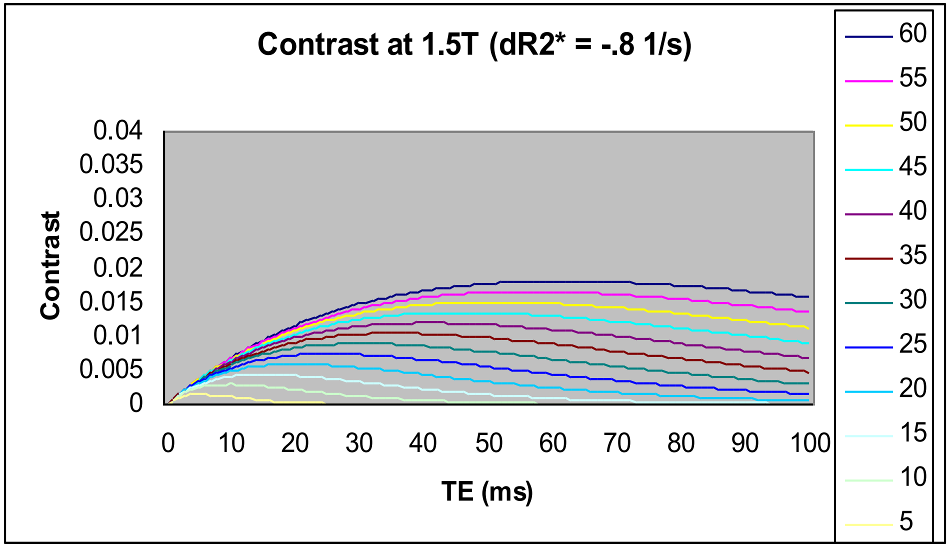
$\Delta R2 = -0.19 \pm 0.02\ s^{-1}$
ΔS_0 (SE) = 1.0 ± 1.0

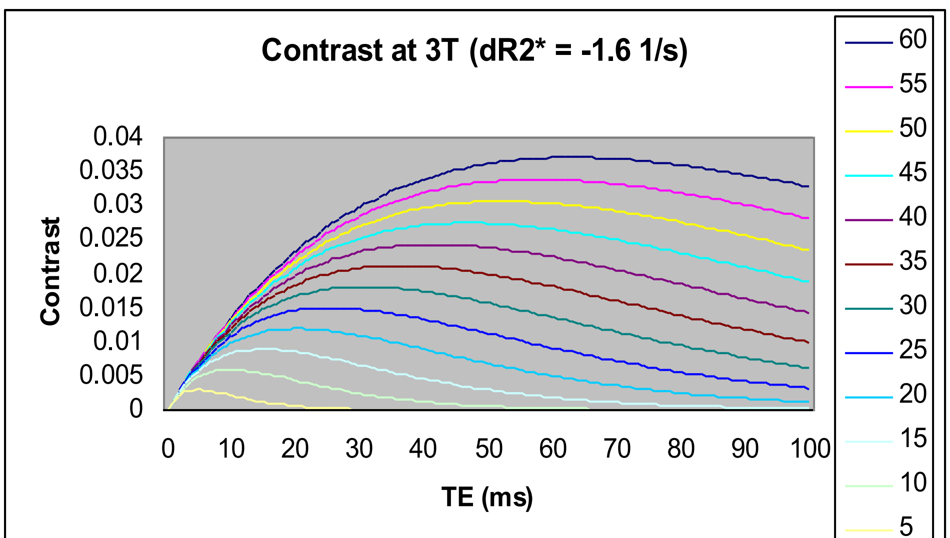


GE int. = 0.64 ± 0.15 %
SE int. = 0.24 ± 0.38 %



Field Strength





SNR ⬆

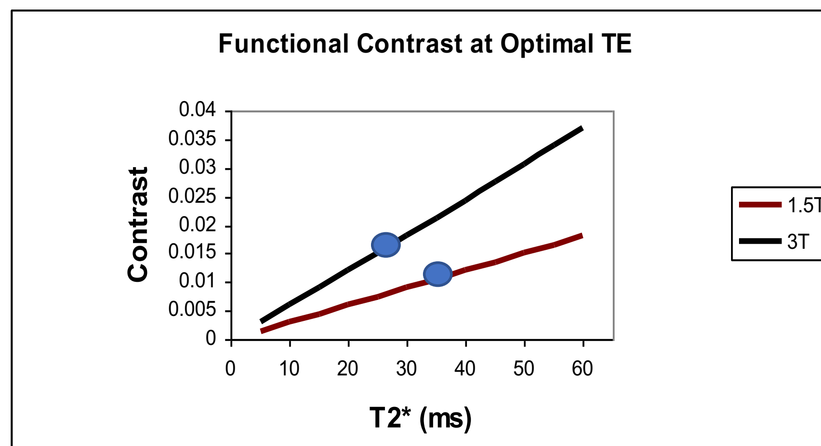
%change ⬆

Physio noise ⬆

CNR ⬆ (depends on physio/thermal)

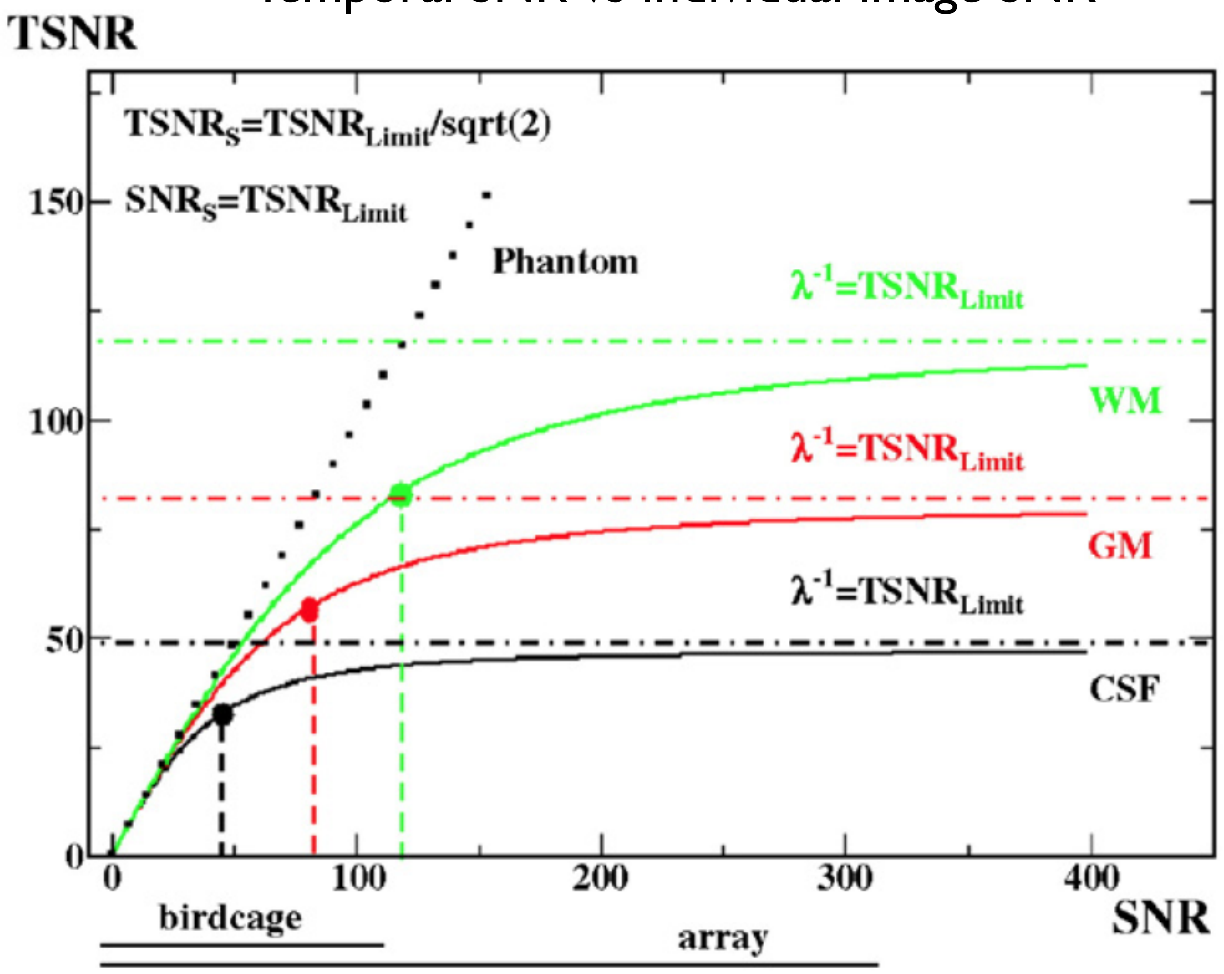
Off-resonance artifacts ⬆

RF power deposition ⬆



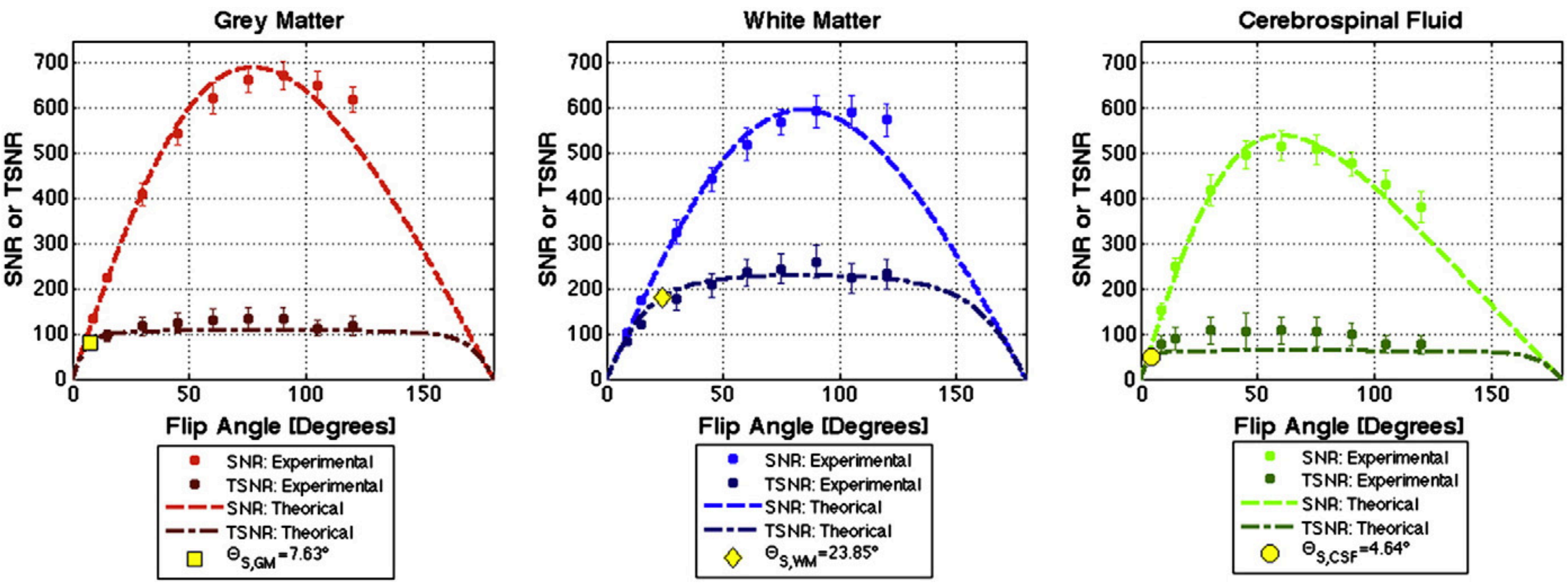
Physiologic Fluctuations

Temporal SNR vs Individual Image SNR



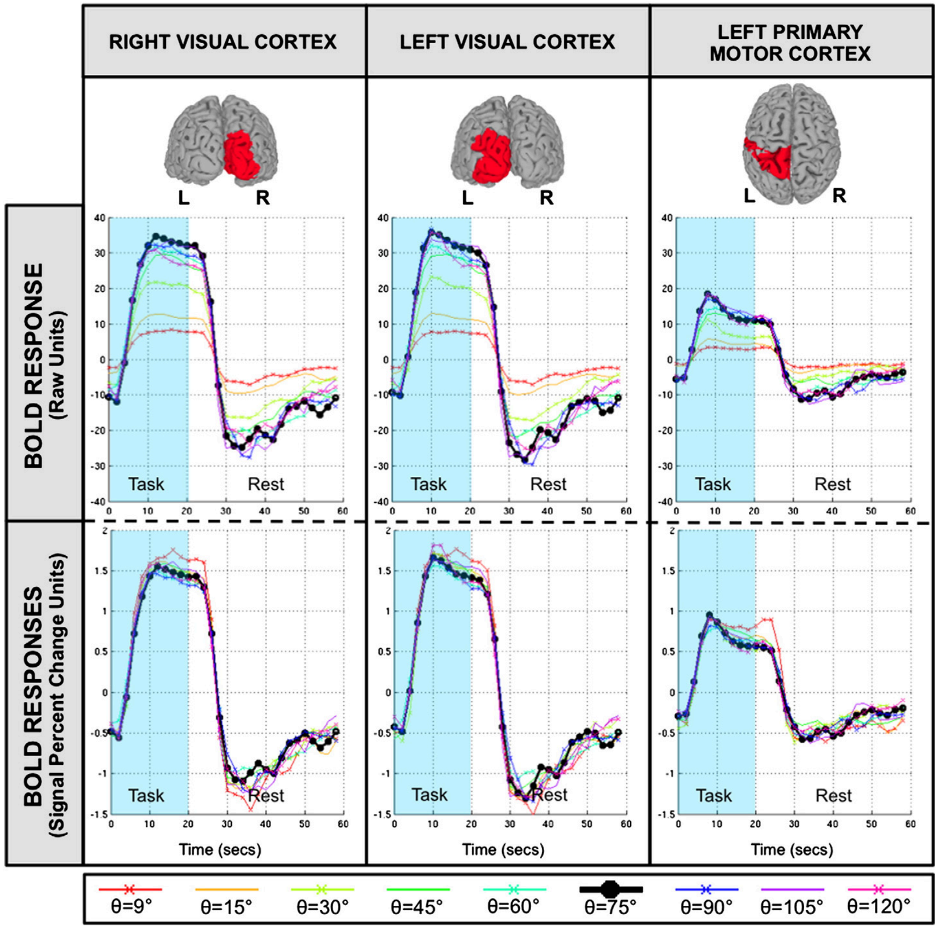
J. Bodurka, F. Ye, N Petridou, K. Murphy, P. A. Bandettini, Mapping the MRI voxel volume in which thermal noise matches physiological noise – implications for fMRI. *NeuroImage,* **34**, 542-549 (2007)

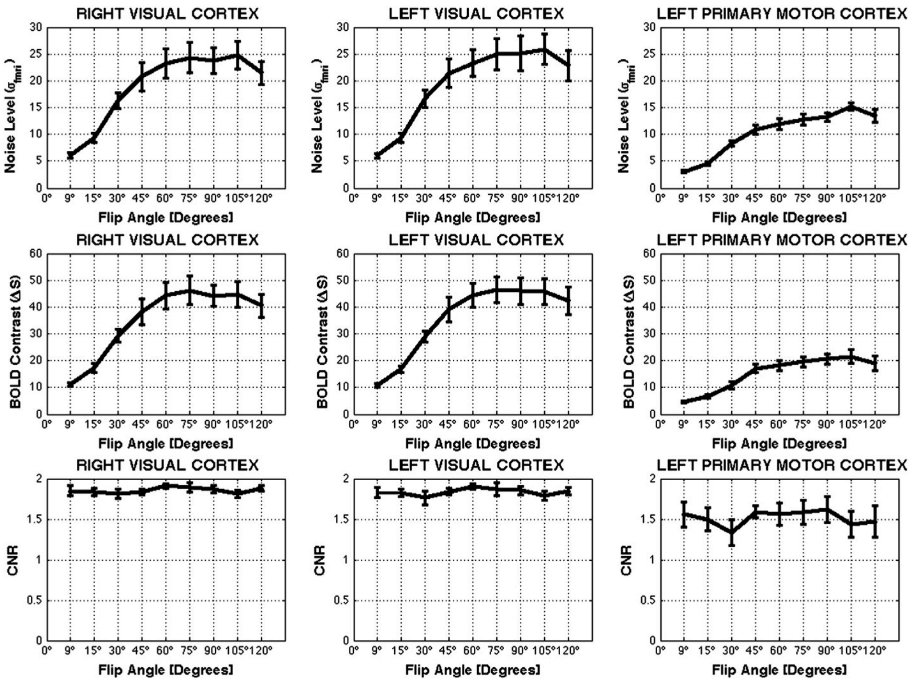
Flip Angle



J. Gonzalez-Castillo, V. Roopchansingh, P. A. Bandettini, J. Bodurka, Physiological noise effects on the flip angle selection in BOLD fMRI. NeuroImage 54 (4) pp. 2764 – 2778. (2011)

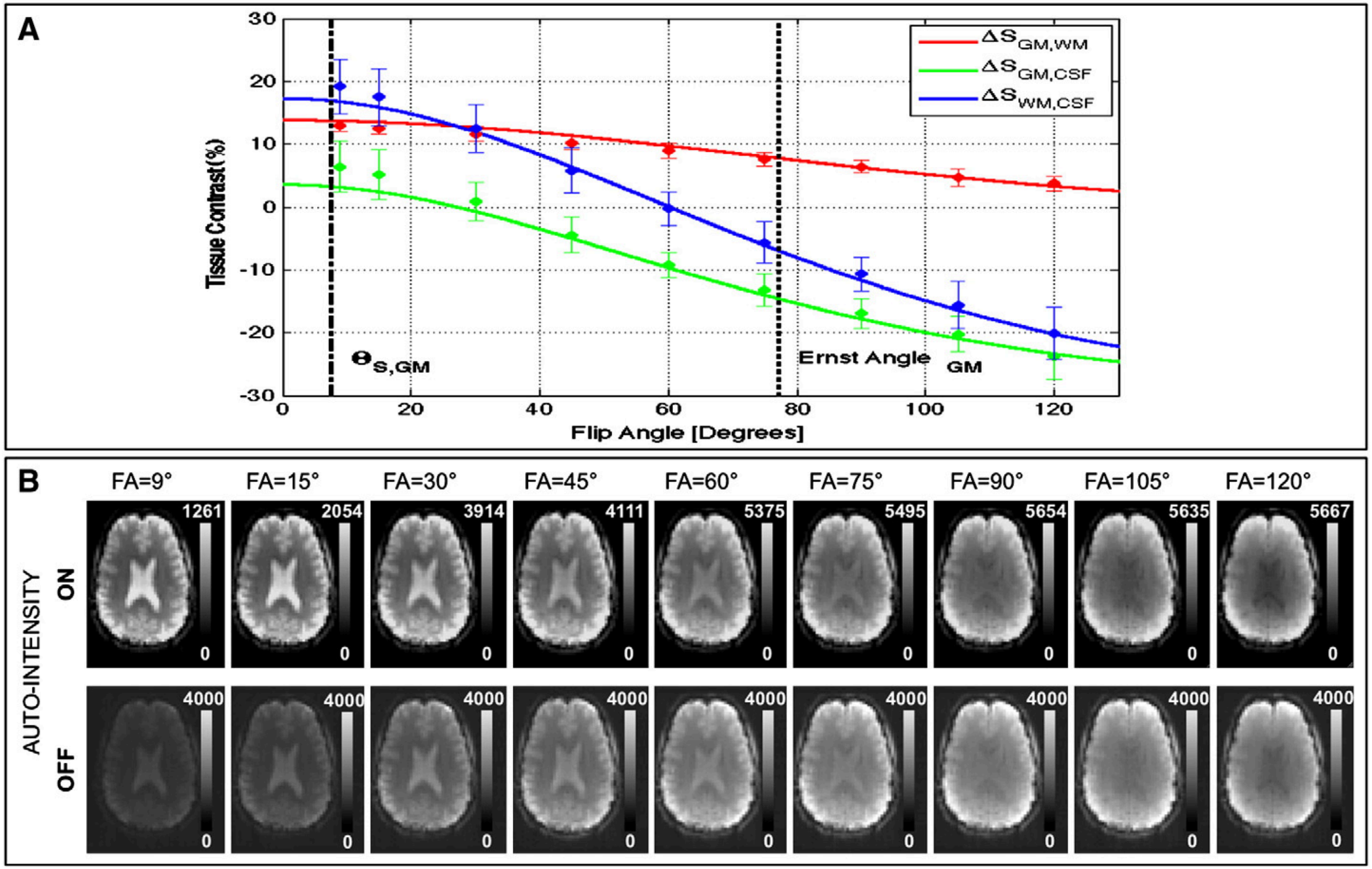
Flip Angle





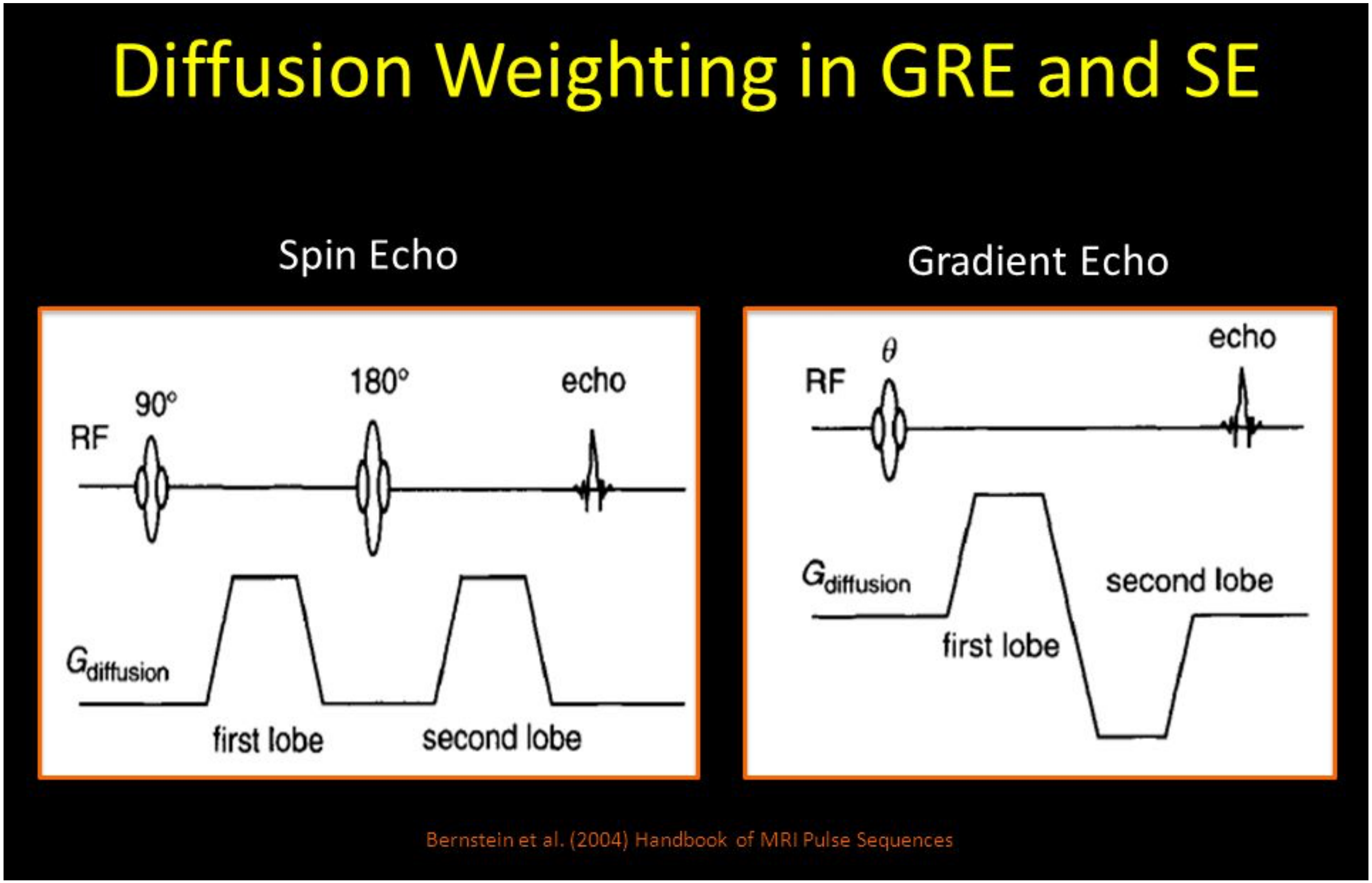
J. Gonzalez-Castillo, V. Roopchansingh, P. A. Bandettini, J. Bodurka, Physiological noise effects on the flip angle selection in BOLD fMRI. NeuroImage 54 (4) pp. 2764 – 2778. (2011)

Flip Angle

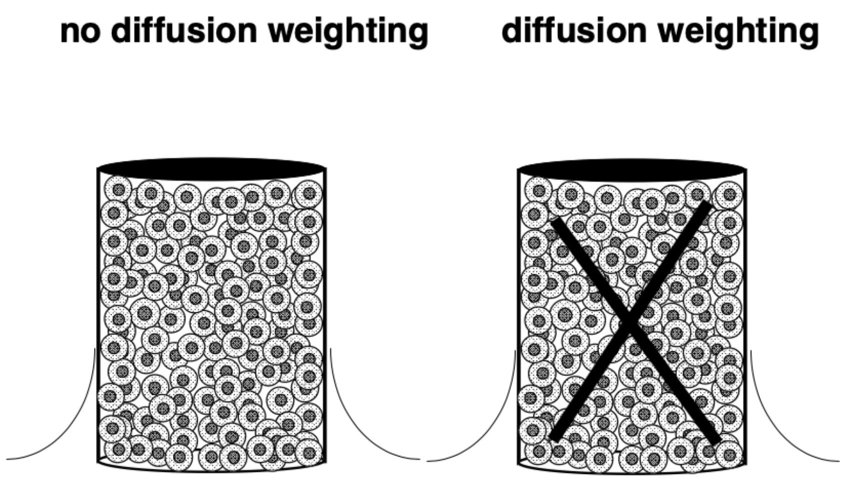


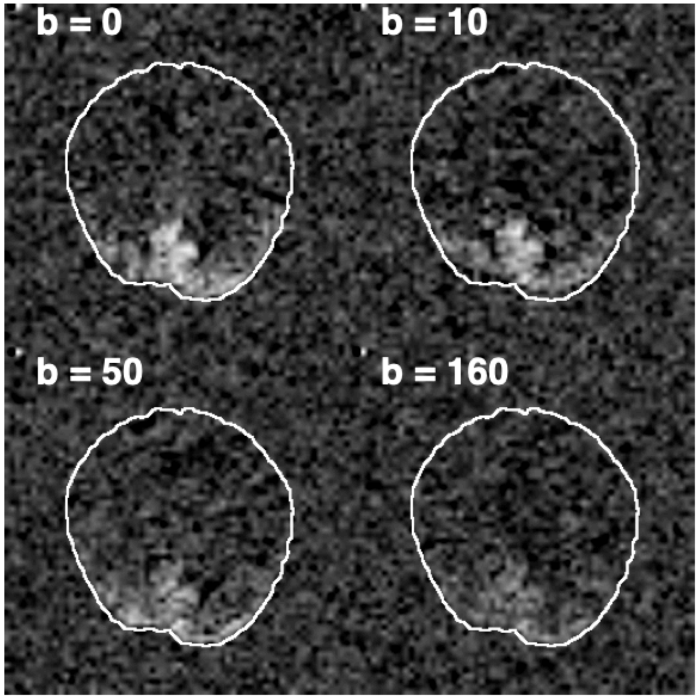
J. Gonzalez-Castillo, V. Roopchansingh, P. A. Bandettini, J. Bodurka, Physiological noise effects on the flip angle selection in BOLD fMRI. NeuroImage 54 (4) pp. 2764 – 2778. (2011)

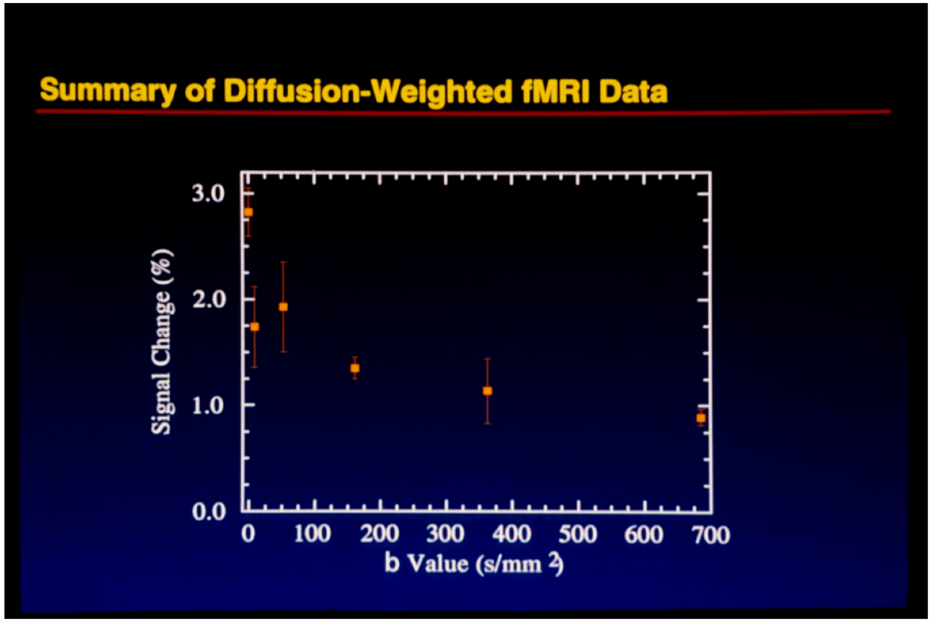
Diffusion Weighting



Diffusion Weighting



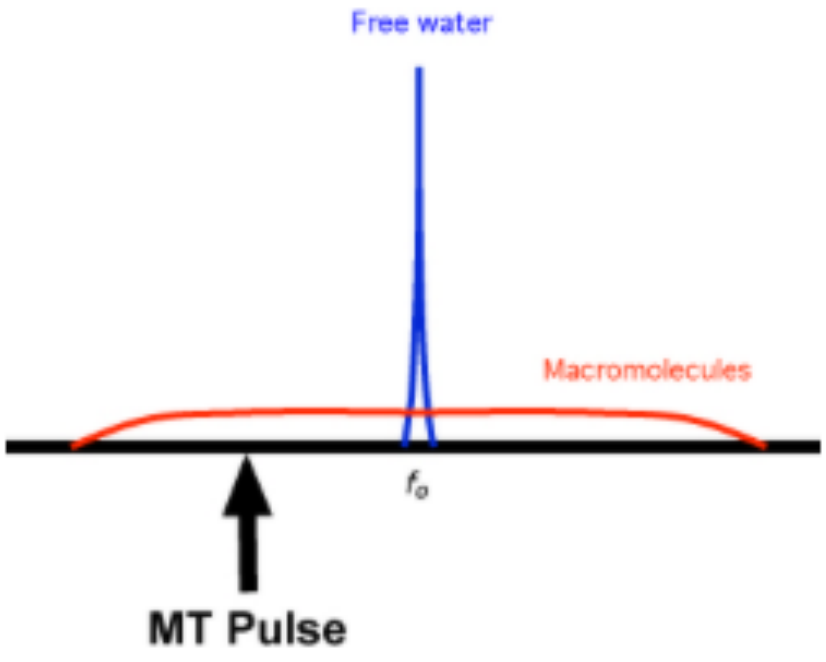


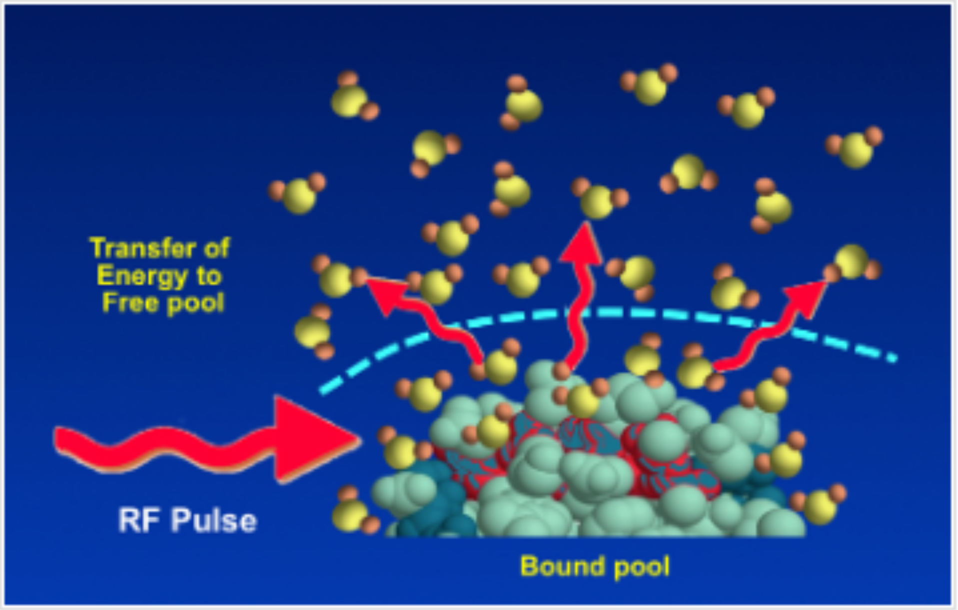


J. L. Boxerman, P. A. Bandettini, K. K. Kwong, J. R. Baker, T. L. Davis, B. R. Rosen, R. M. Weisskoff, The intravascular contribution to fMRI signal change: monte carlo modeling and diffusion - weighted studies in vivo. Magn. Reson. Med. 34, 4-10 (1995).

Magnetization Transfer Pulses

Removes extravascular (macromolecule) signal

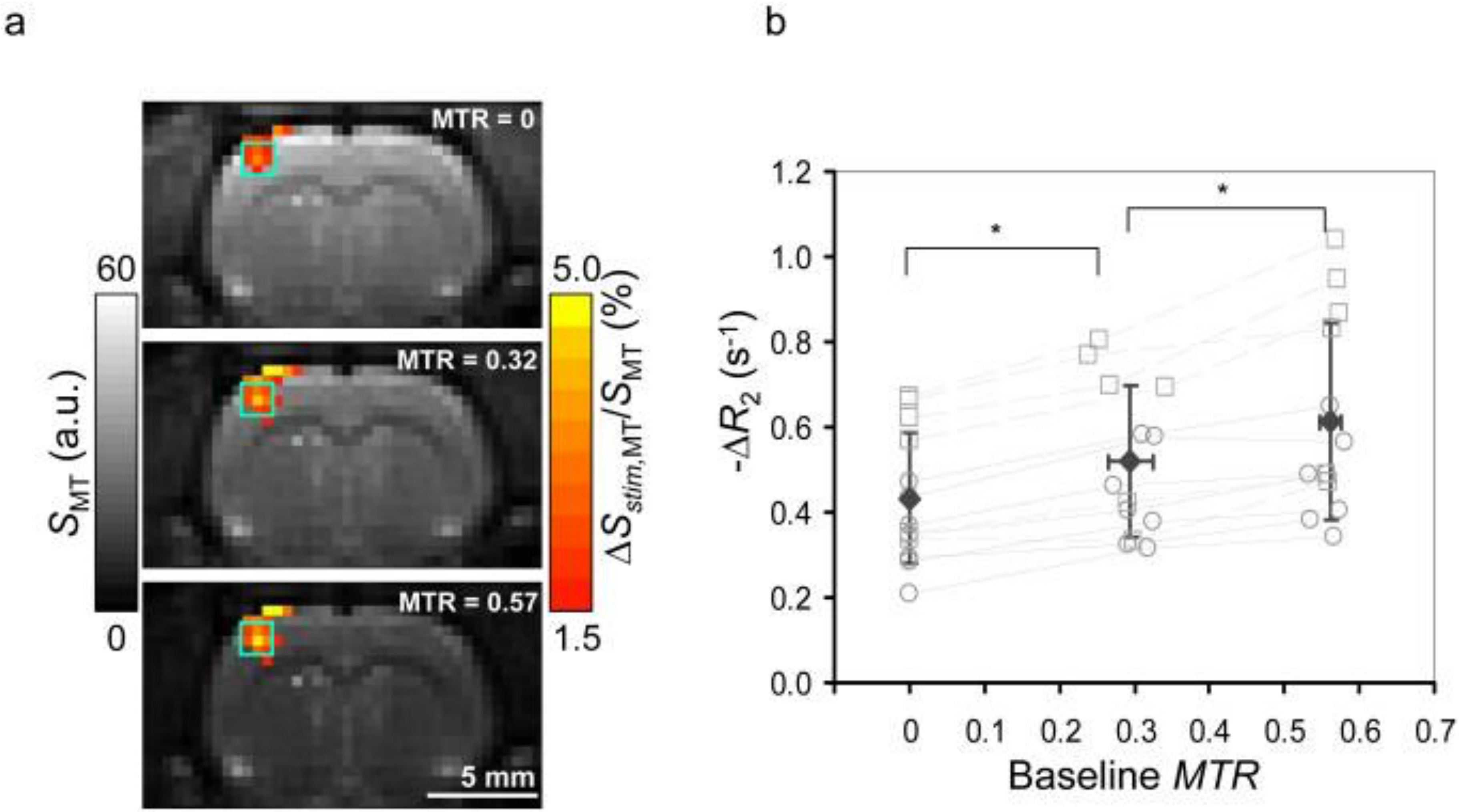




Magnetization transfer. An specially designed RF pulse (called an **MT Pulse**) is applied which selectively injects energy into the bound pool of protons (macromolecules and bound water). This energy is then transferred (primarily by dipolar interactions) to the free water pool, partially saturating it.

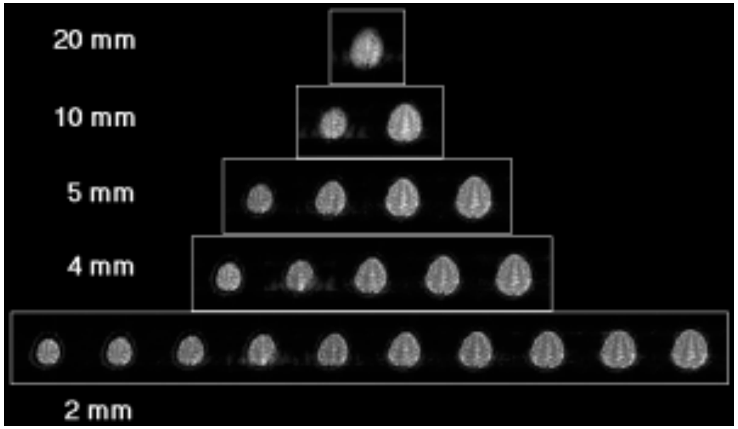
http://mriquestions.com/magnetization-transfer1.html

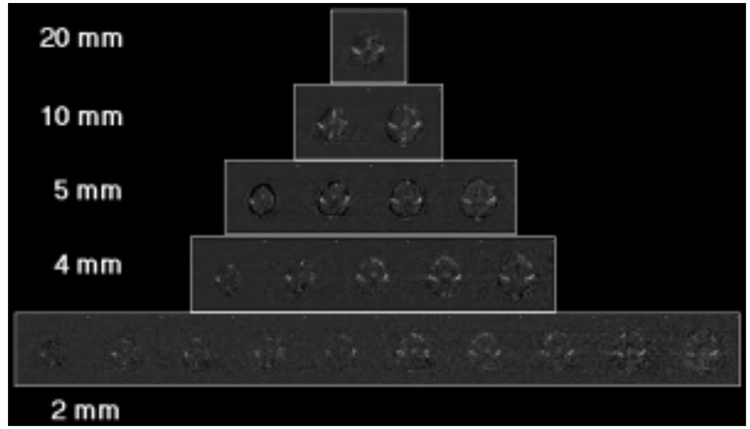
Magnetization Transfer Pulses

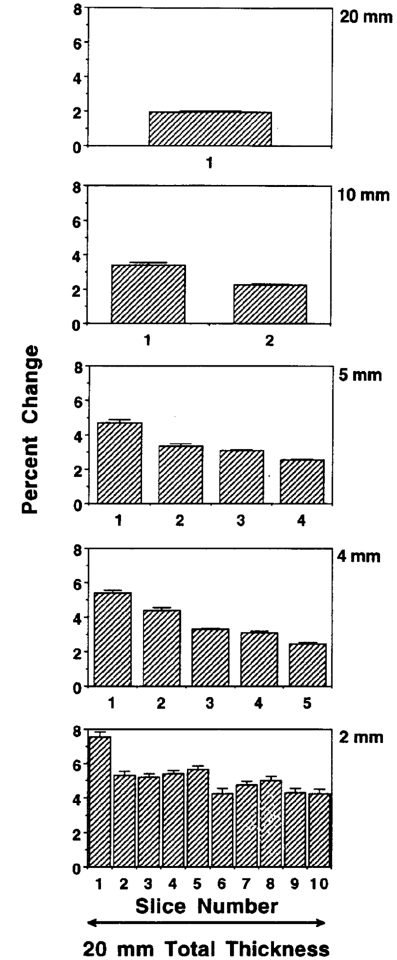


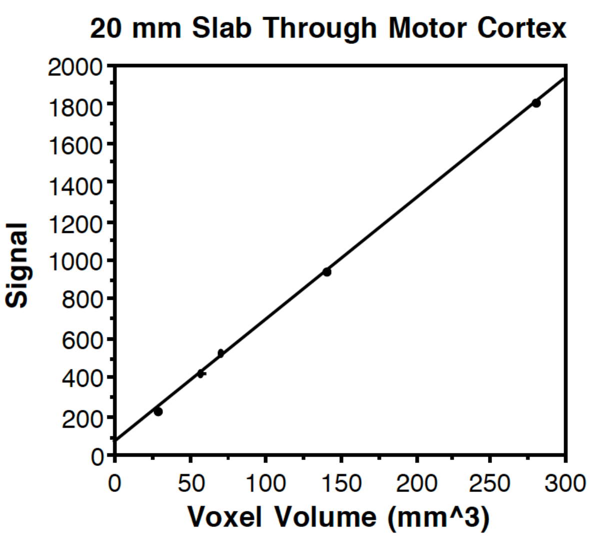
Kim, Hendrich, Kim, MRM 2008

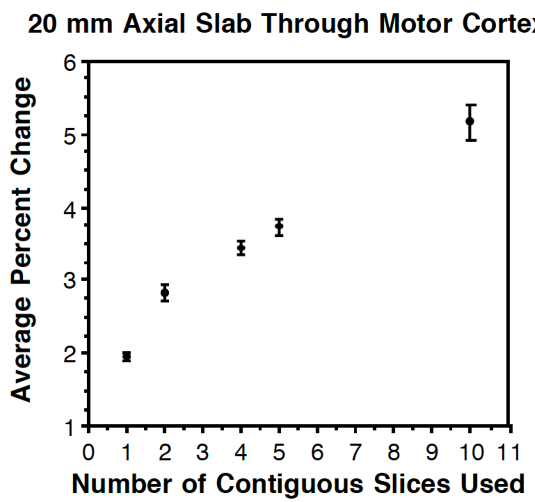
Slice Thickness





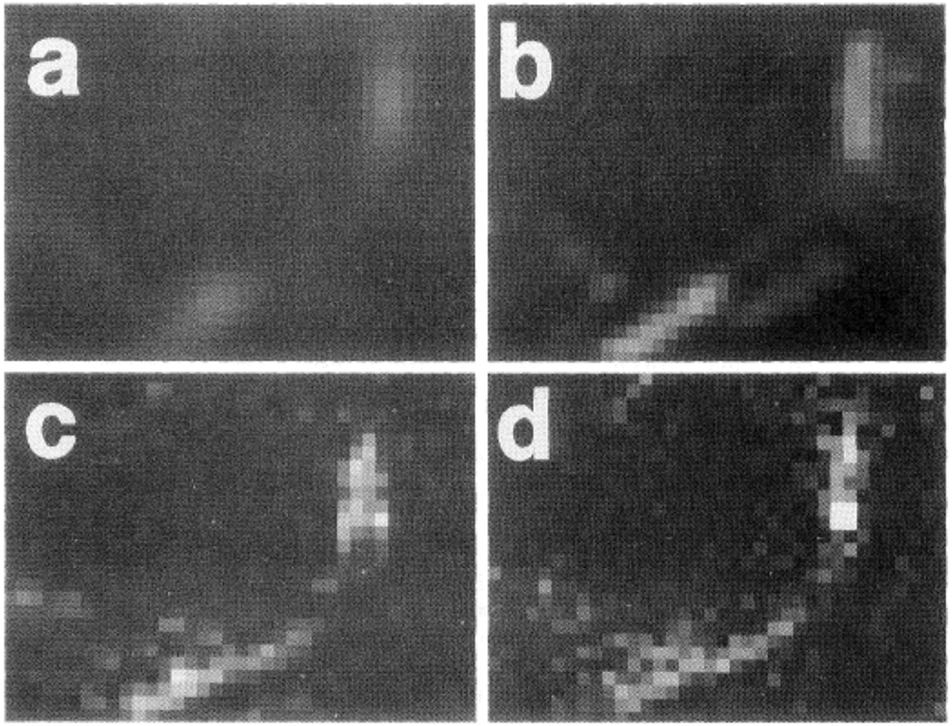




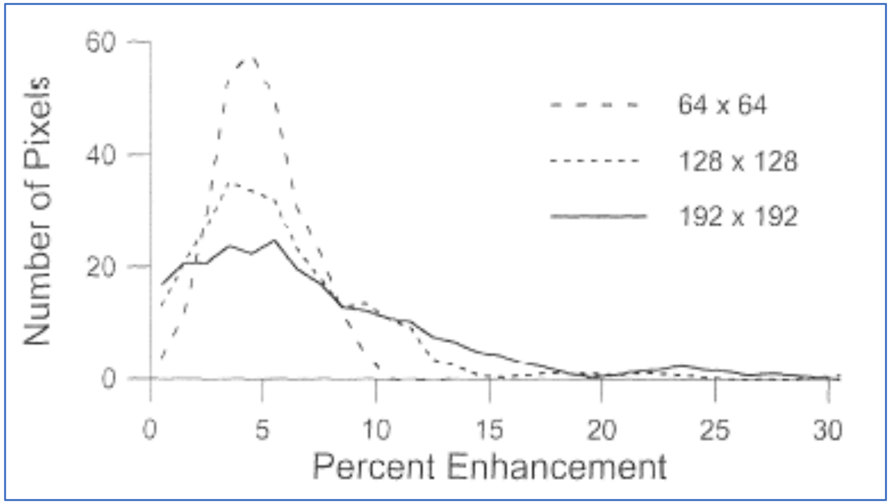


Voxel Dimension

2.5mm^2 1.25mm^2

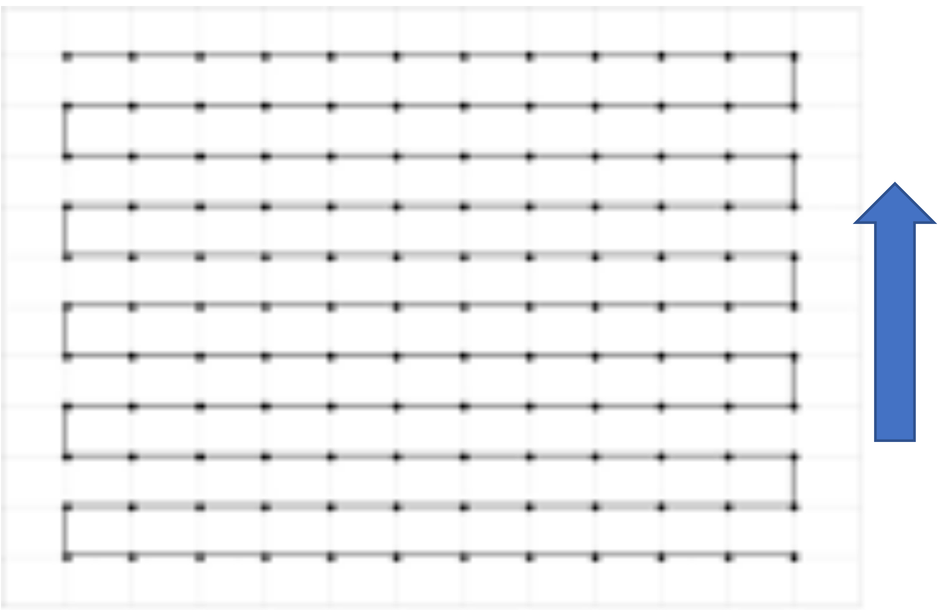


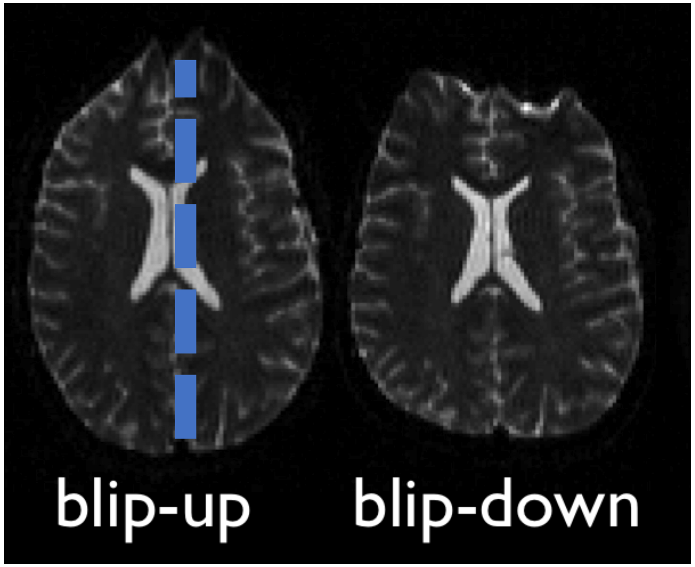
0.83 mm^2 0.62 mm^2



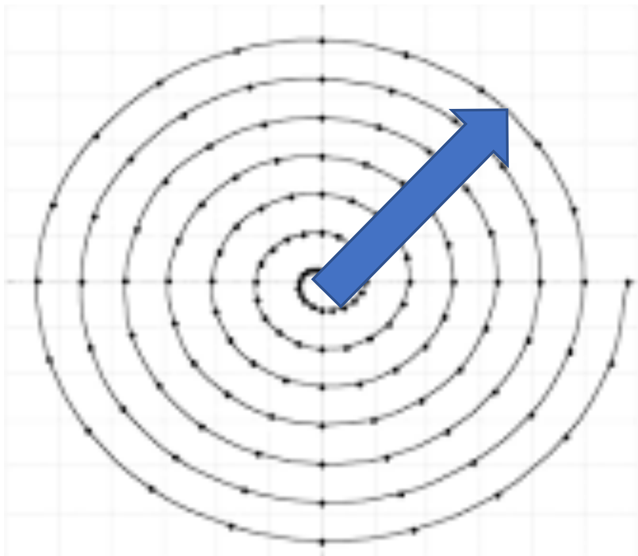
A. Jesmanowicz, P. A. Bandettini, J. S. Hyde, Single shot half k-space high resolution EPI for fMRI at 3T. Magn. Reson. Med. 40, 754-762 (1998).

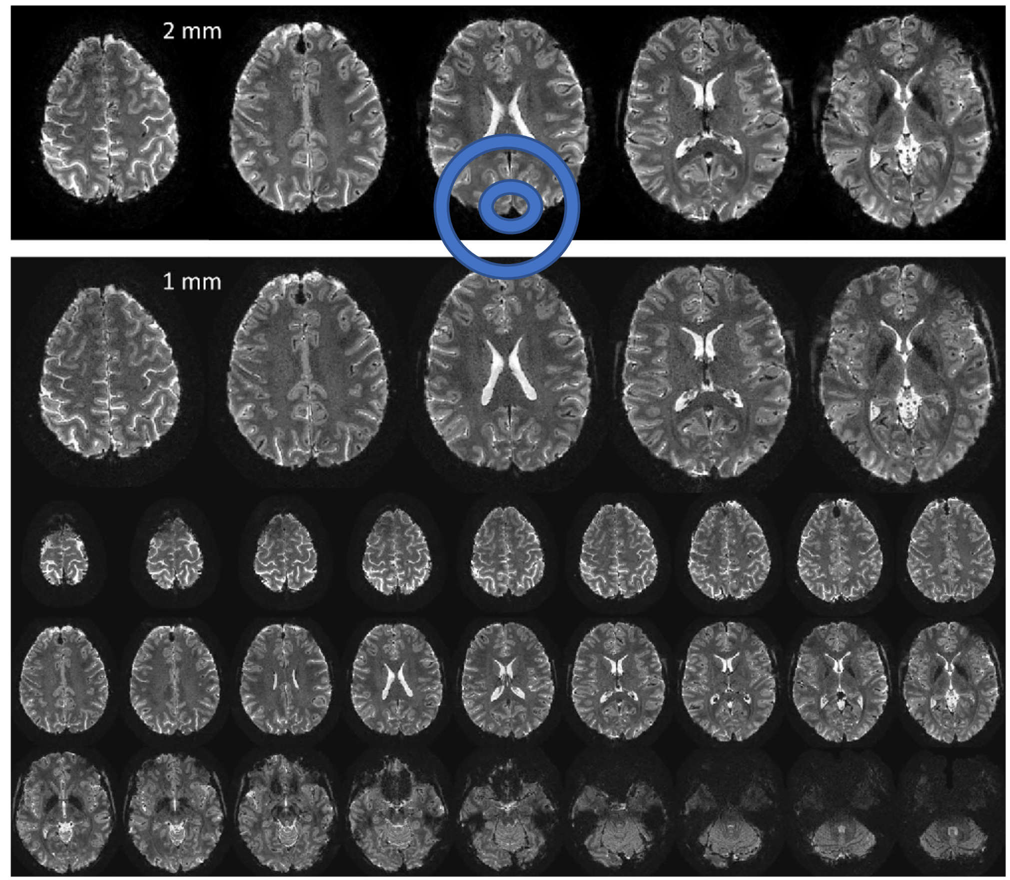
Readout Direction





Readout Direction



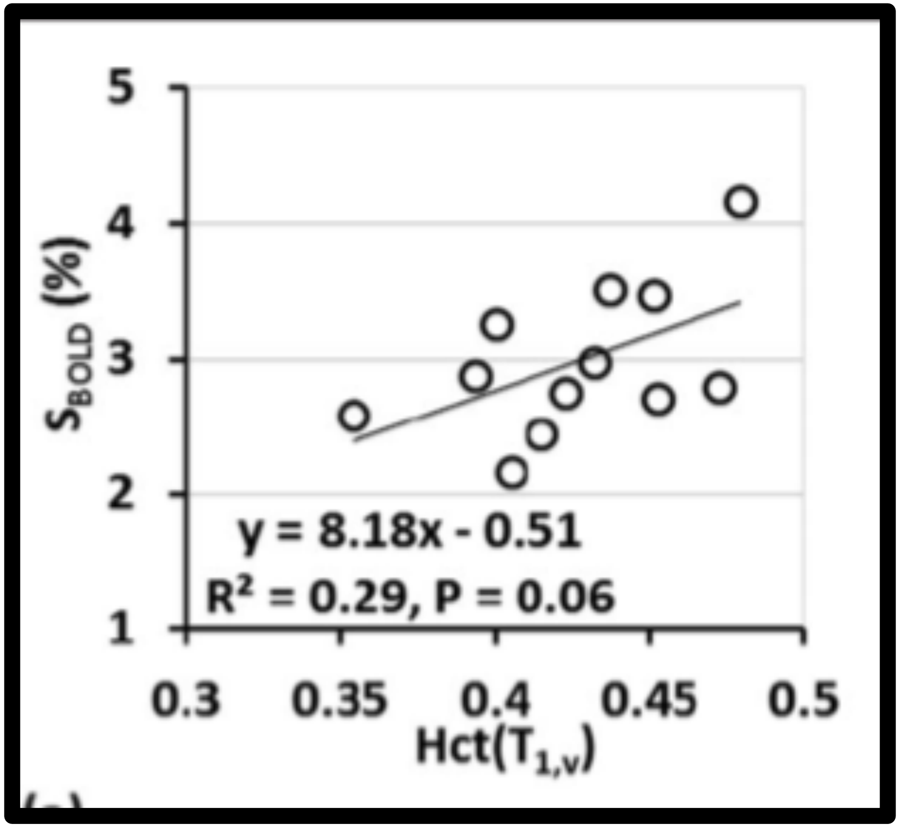


Spiral-out imaging with TE = 25 ms, 0.8 mm nominal resolution. The bottom panel displays the central 27 of 36 slices

What Physiological Parameters Influence the fMRI signal?

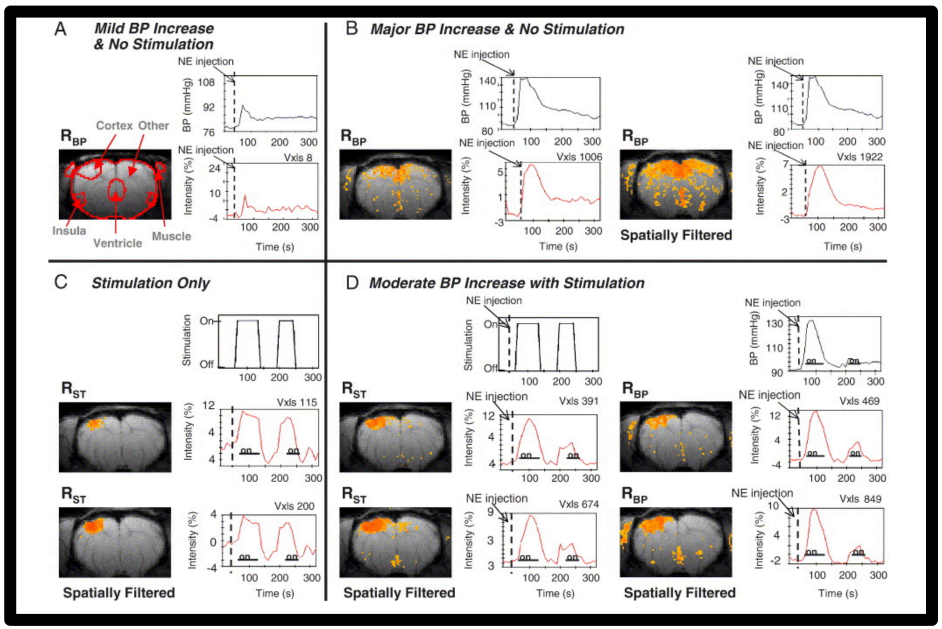
- Hematocrit
- Blood pressure
- Blood volume in each voxel
- Neurovascular responsivity
- Drug effects

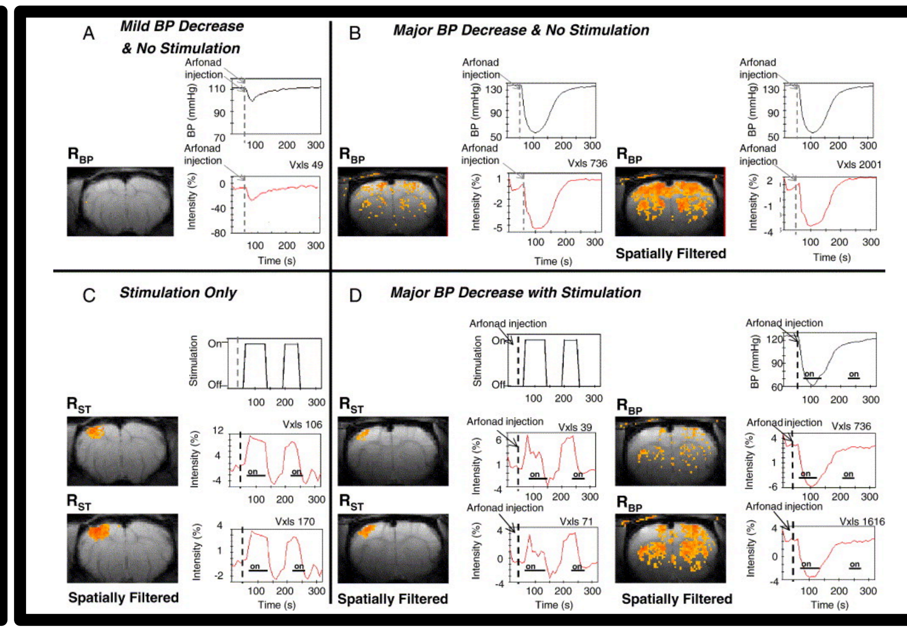
Hematocrit



Xu, Li, et al. HBM 39:3-44-353 (2018)

Blood pressure

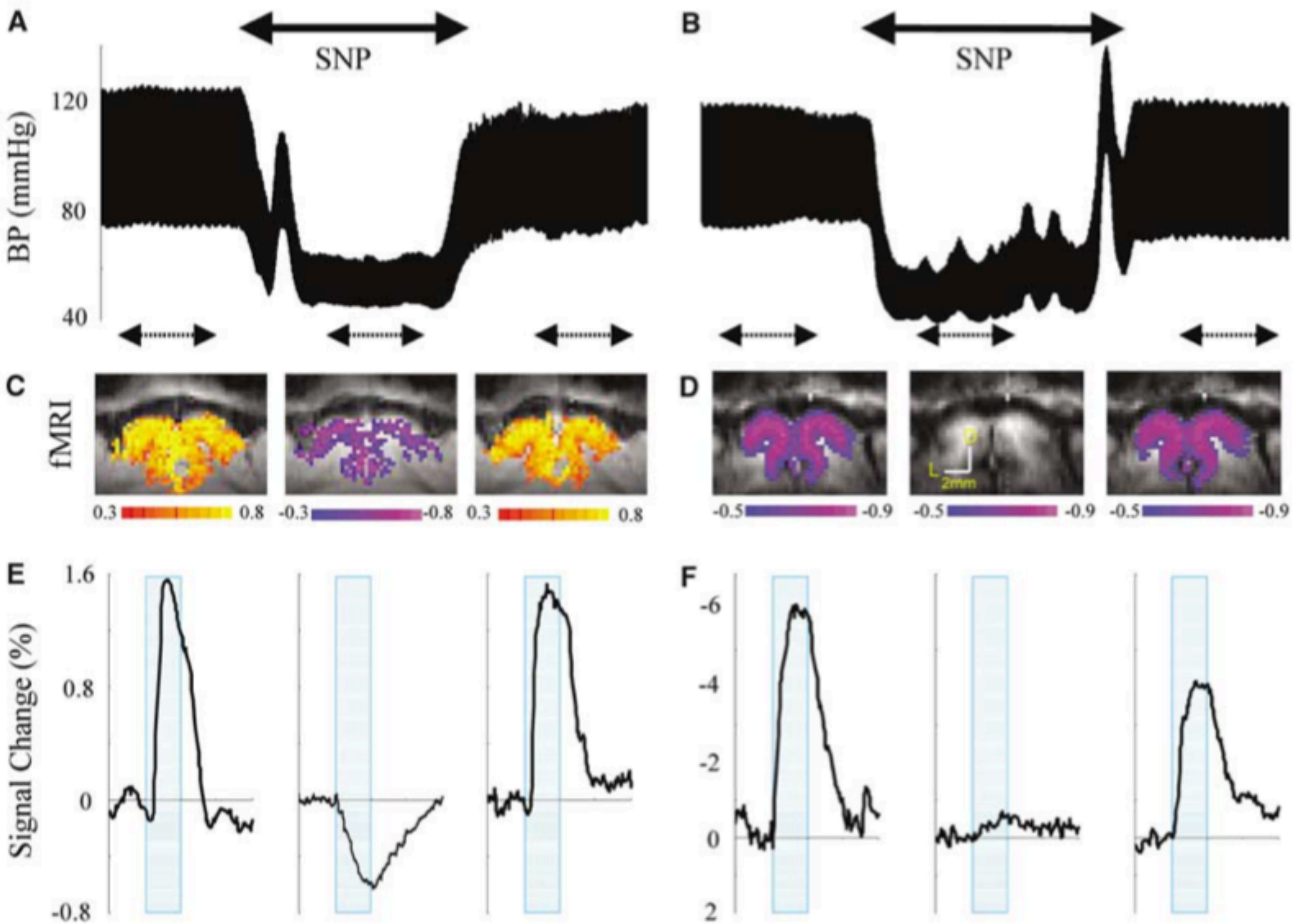




Wang, Foniok, et al. NeuroImage 2006

Blood pressure

Sodium Nitroprusside



BOLD **Blood Volume**

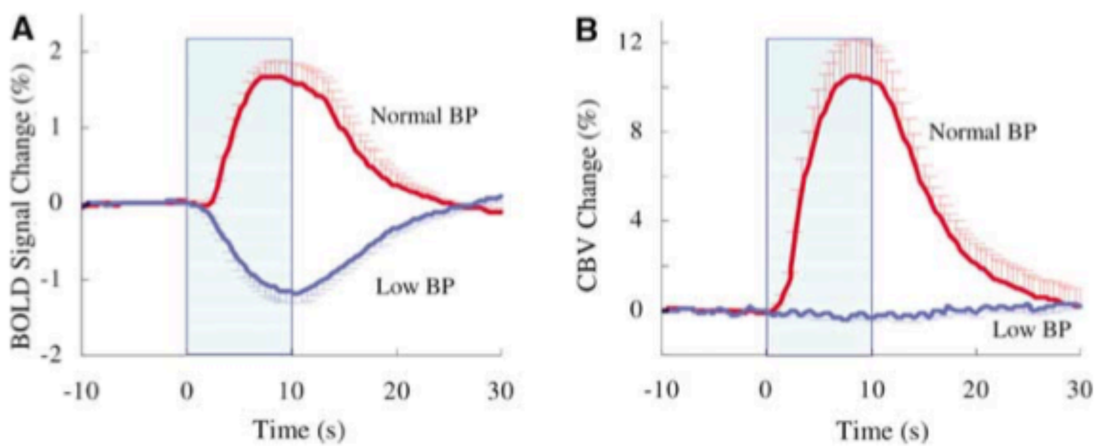
Nagaoka, et al. JCBFM 2006

Blood pressure

Table 1 Vascular physiological variables (mean ± s.d., $n = 5$)

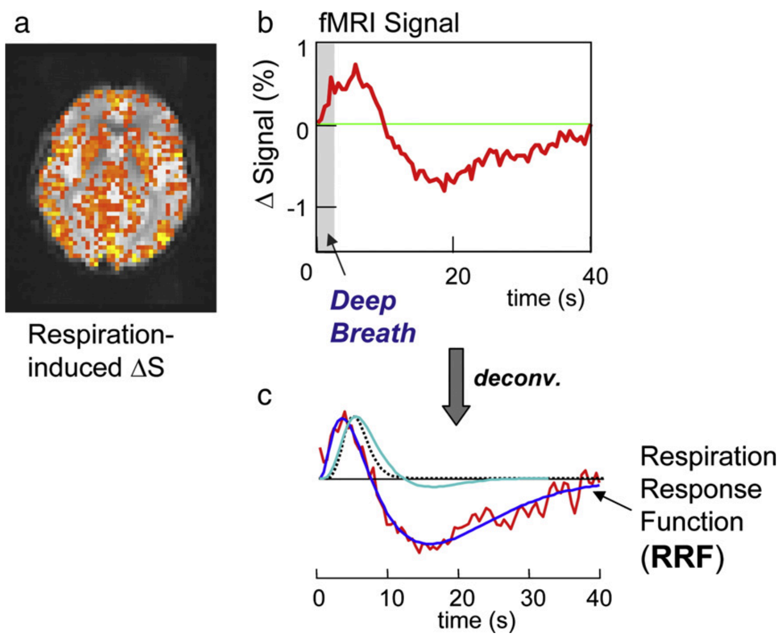
		BOLD studies			*CBV studies*		
		Normal BP	*Low BP*	*Recovery*	*Normal BP*	*Low BP*	*Recovery*
Systolic	ABP	128.6 ± 6.9	64.4 ± 7.7*	119.0 ± 12.1	120.6 ± 8.9	70.0 ± 3.4*	118.2 ± 6.8
Diastolic	ABP	82.0 ± 9.8	38.6 ± 2.3*	76.0 ± 6.0	72.8 ± 11.8	40.6 ± 2.2*	68.6 ± 3.1
Mean	ABP	97.5 ± 8.5	47.2 ± 3.9*	90.3 ± 7.3	88.7 ± 10.4	50.4 ± 1.4*	85.1 ± 3.5
Heart	Rate	179.8 ± 11.9	173.6 ± 15.3	171.2 ± 16.4	176.0 ± 9.4	179.0 ± 14.4	174.6 ± 14.4

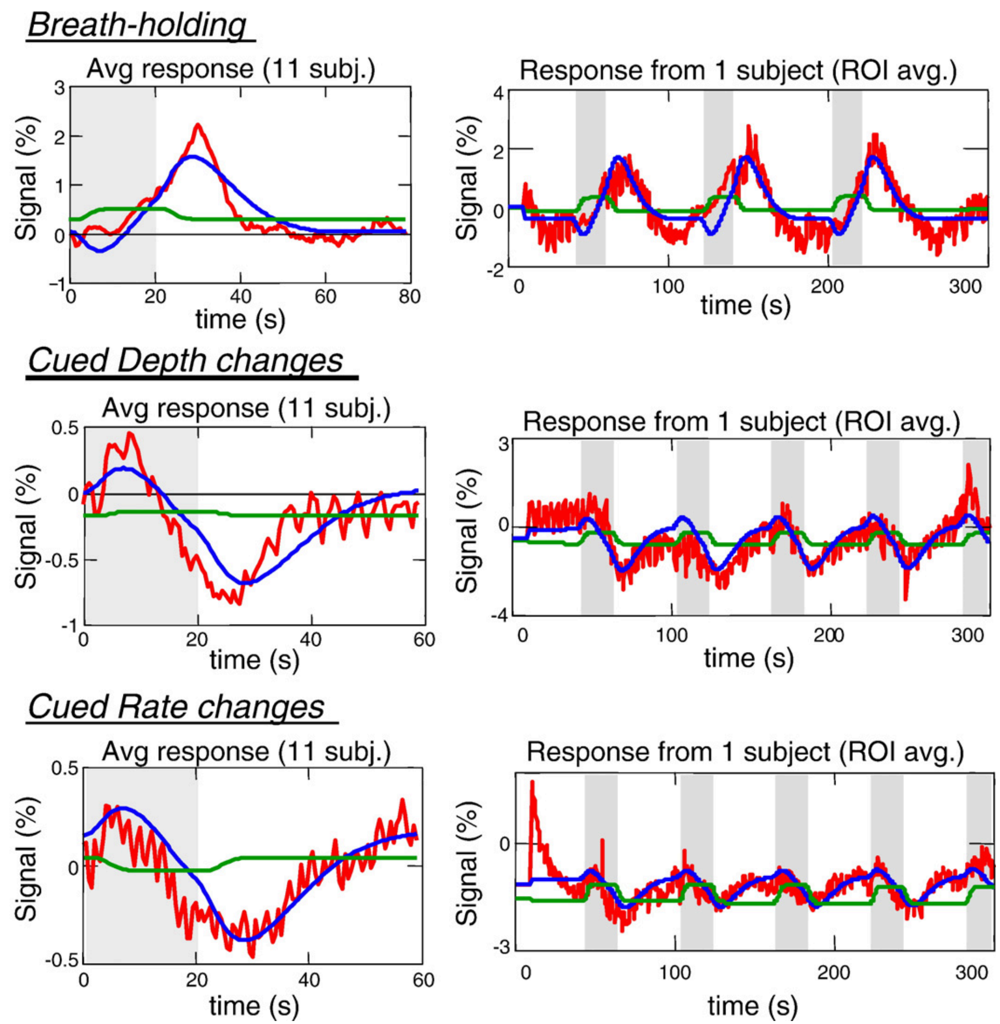
Arterial blood pressure (ABP) is in units of mm Hg, and heart rate is beats/min. Heart rate was obtained from arterial blood pressure data. *Significant differences (single-factor ANOVA) among the six experiments with $P < 0.01$.

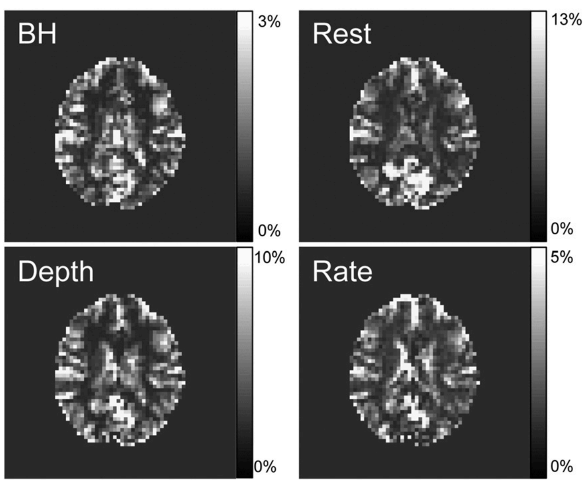


Nagaoka, et al. JCBFM 2006

Respiration

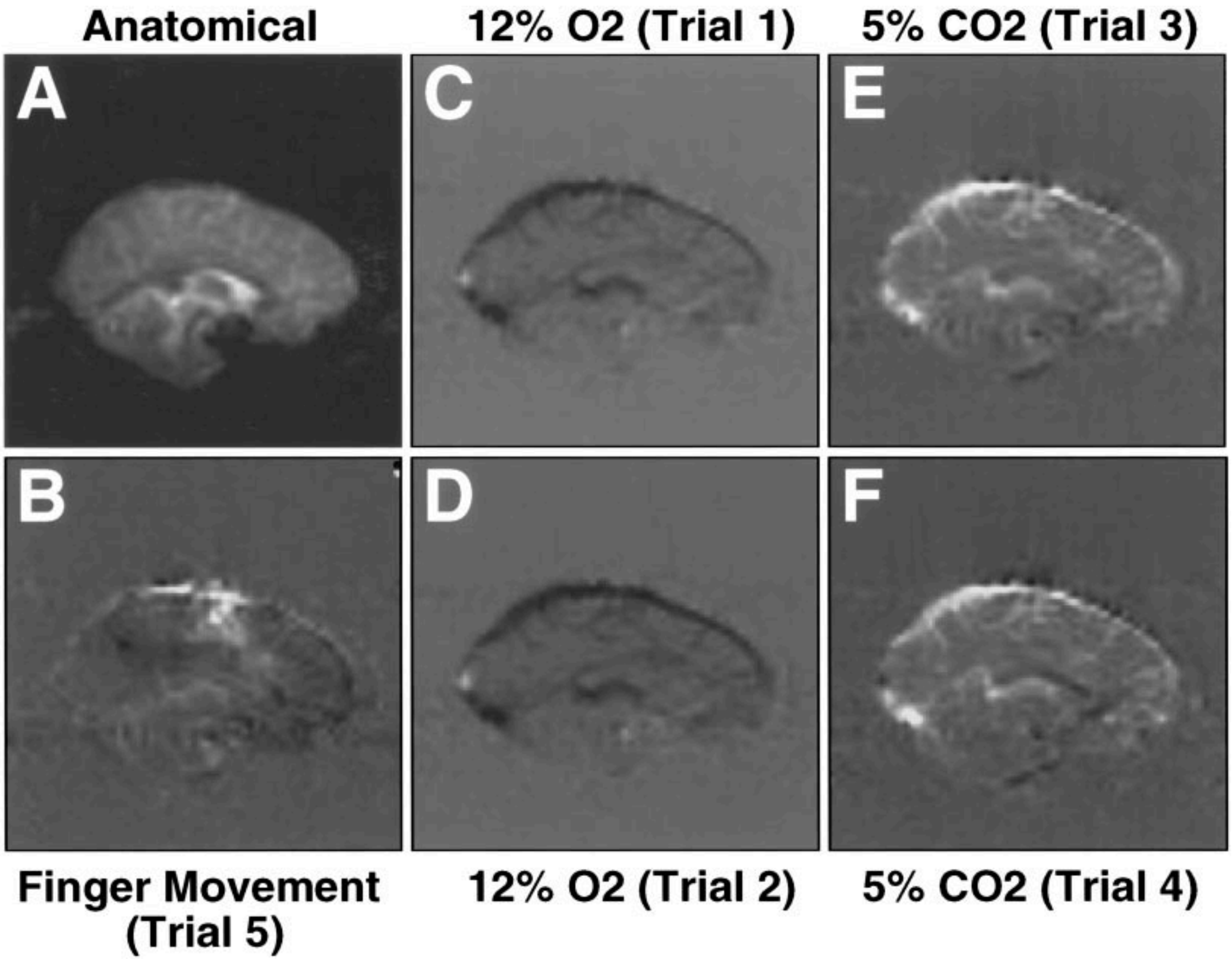




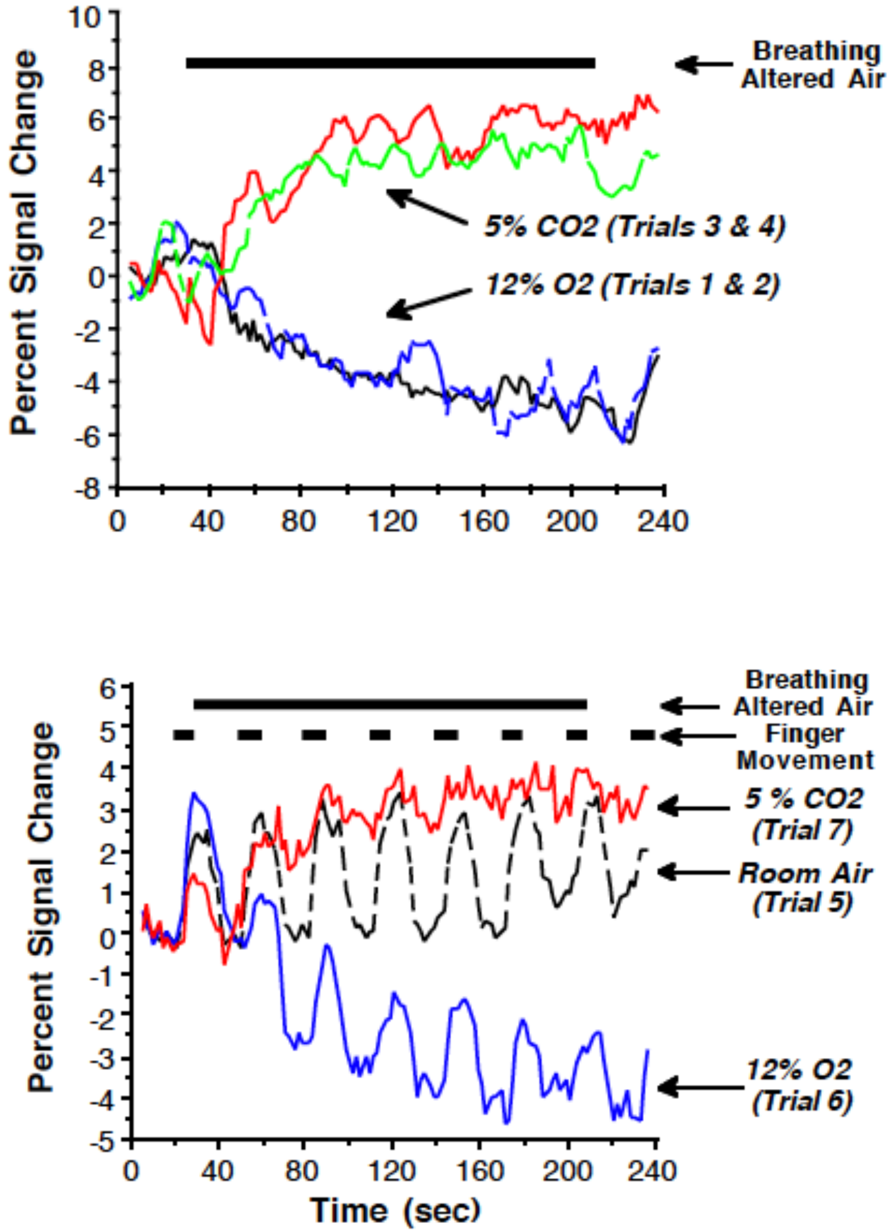


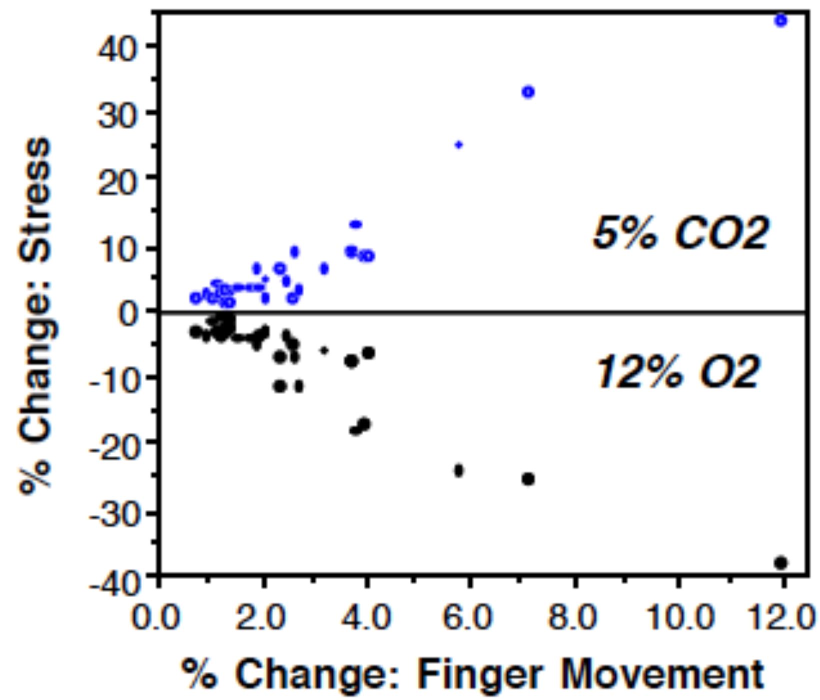
Birn et al. NeuroImage 2008

Blood Volume



Blood Volume





Bandettini et al. NMR in Biomedicine 1997

Neurovascular Responsivity

Neurobiology of Aging 34 (2013) 1469–1485

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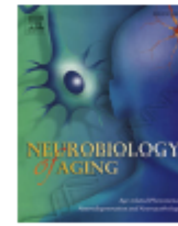


Age dependence of hemodynamic response characteristics in human functional magnetic resonance imaging

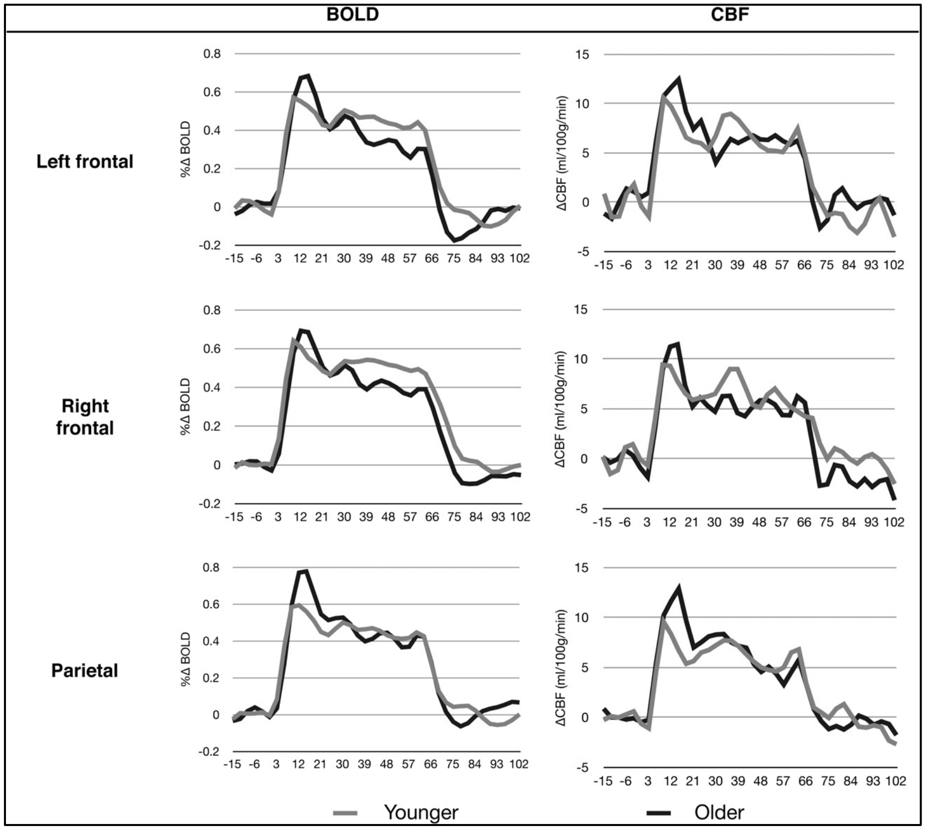
Claudine J. Gauthier [a,b,*], Cécile Madjar [b], Laurence Desjardins-Crépeau [b,c], Pierre Bellec [b,d], Louis Bherer [b,c], Richard D. Hoge [a,b]

[a] Physiology/Biomedical Engineering, Université de Montréal, Montreal, Quebec, Canada
[b] CRIUGM, Montreal, Quebec, Canada
[c] Psychology Department, UQAM, Montreal, Quebec, Canada
[d] Computer Science and Operations Research, Université de Montréal, Montreal, Quebec, Canada

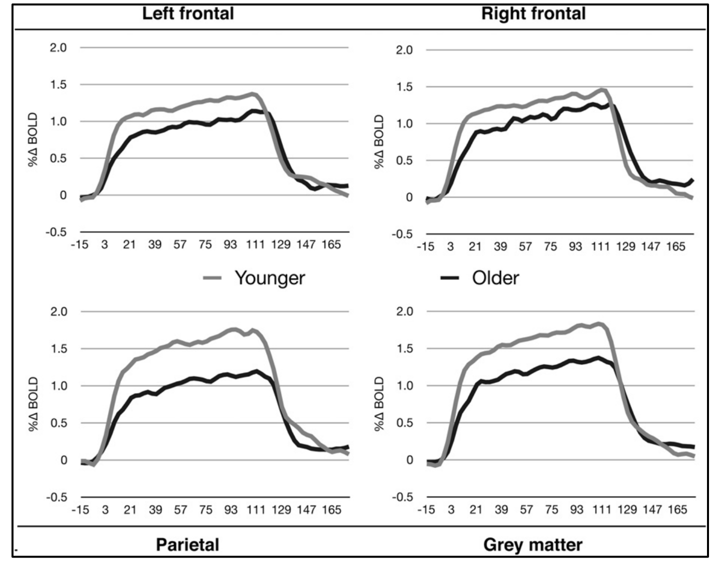
Neurovascular Responsivity

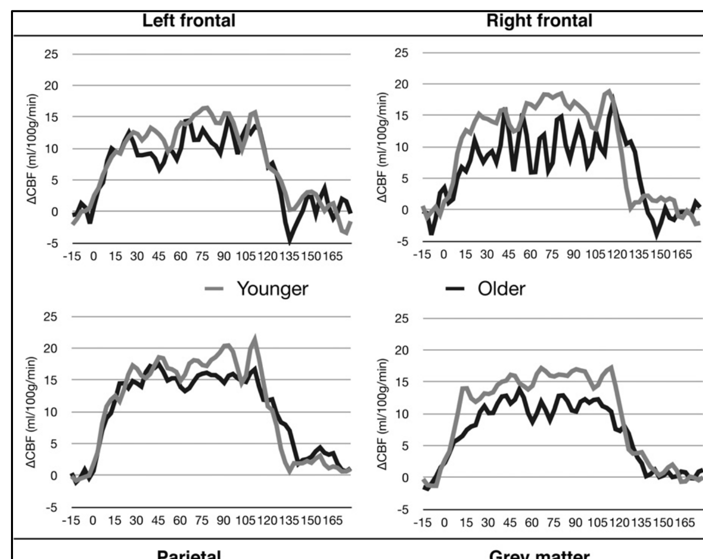
Aging

Response to modified Stroop task



Response to Hypercapnia

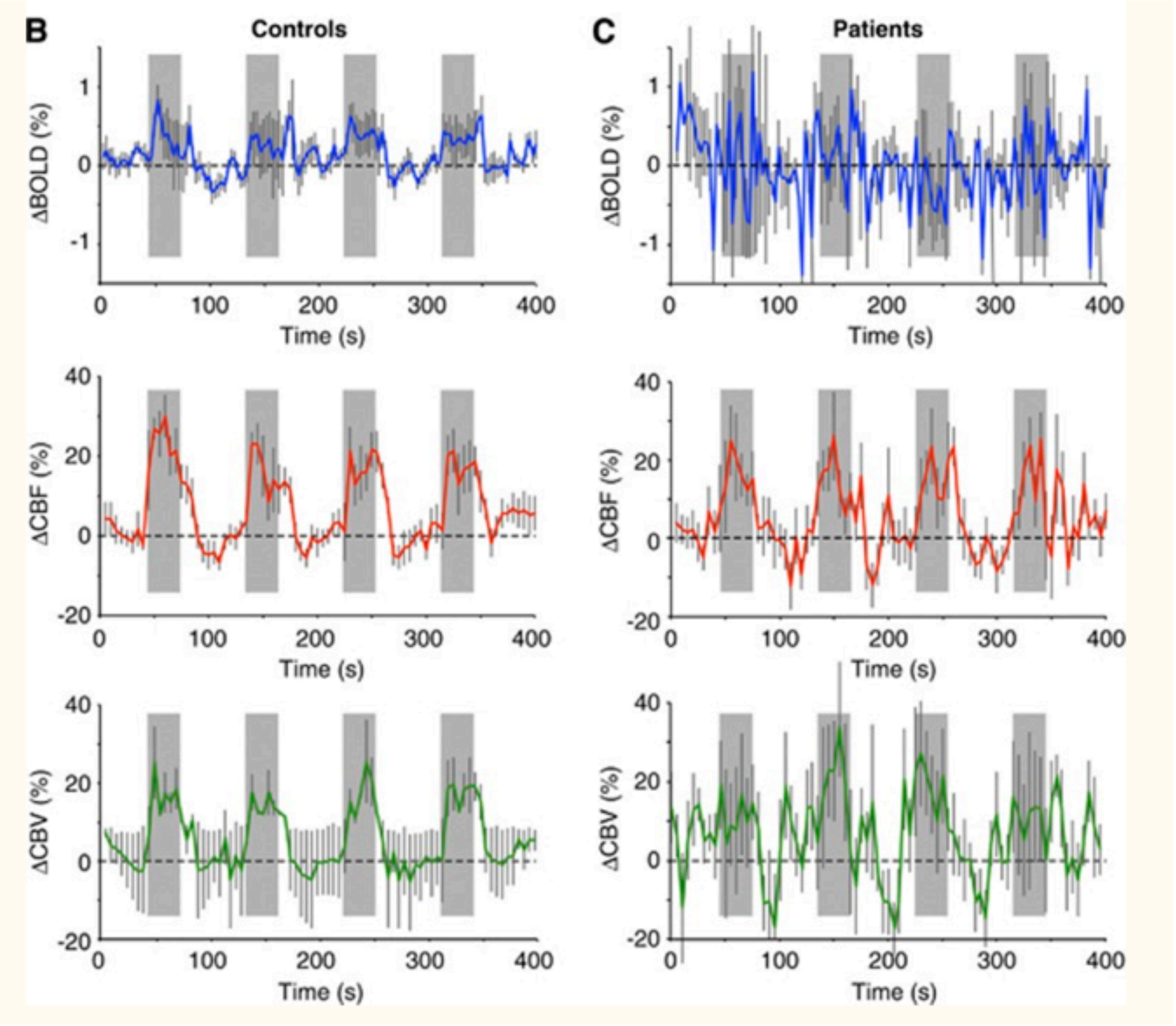




...leads to a potential underestimation of neuronal activity in older adults

Neurovascular Responsivity

Stroke



Drug Effects

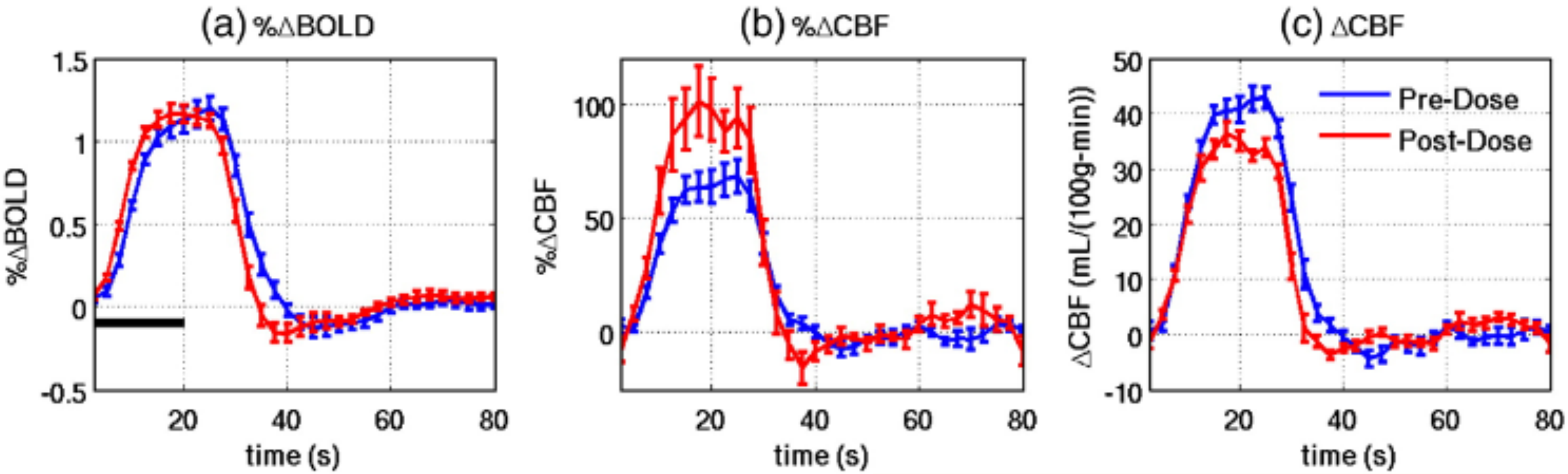
Drug-Induced Changes in Brain Activity

In the first approach, BOLD signal can conceivably be modified by any pharmacological influence on cerebral blood flow, cerebral blood volume, and cerebral metabolic oxygen consumption. There are four principal drug effects which may be seen individually or in combination:

1. Regional changes associated with modified neuronal activity mediated by intact neurovascular coupling.
2. Regional changes associated with modified non-neuronally-induced metabolic activity, such as may result from local drug binding.
3. Regional or global changes in vascular tone and hence cerebral blood flow and volume.
4. Global changes in cerebral blood flow or volume arising from altered heart rate, blood pressure, or breathing.

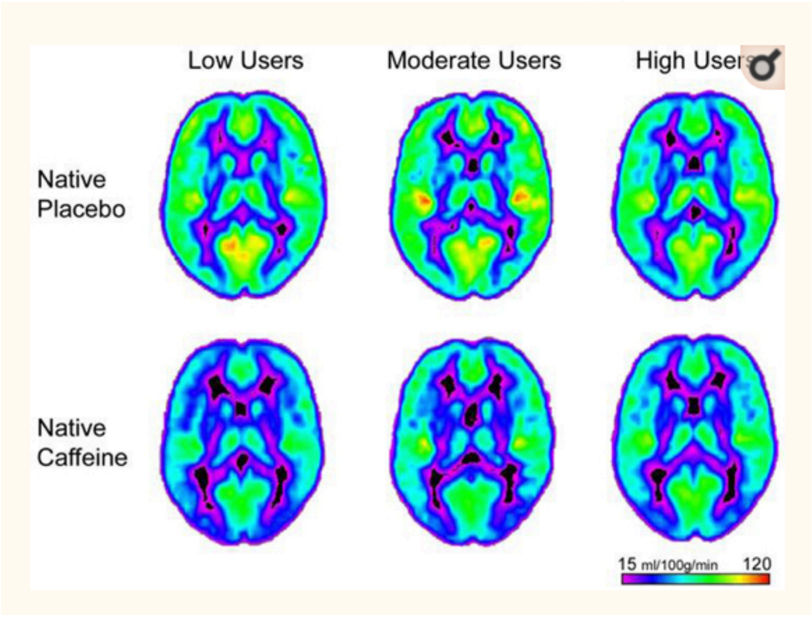
Caffeine

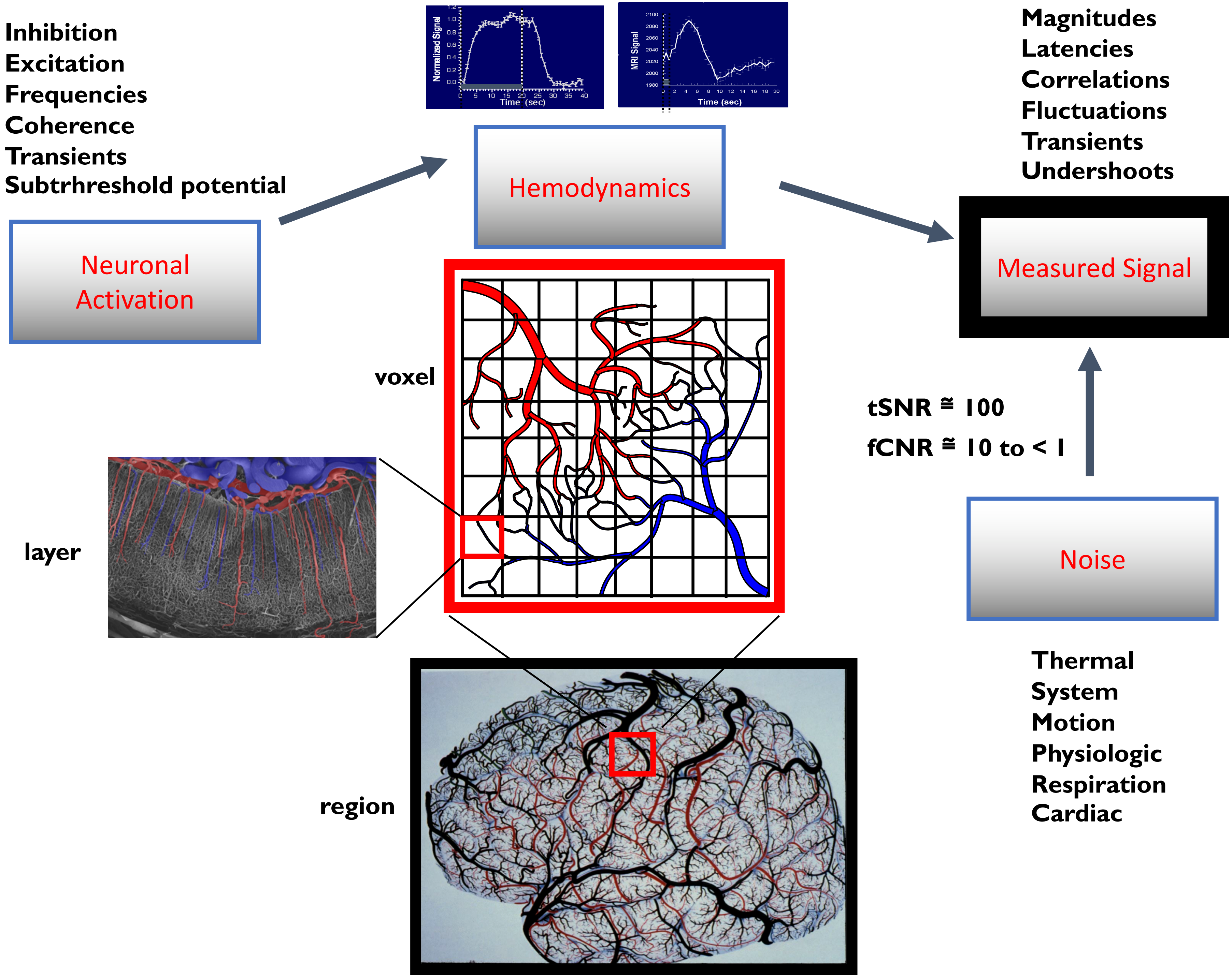
Drug Effects



Liau, Perthen, Liu, NeuroImage 2008

Addicott, et al. HBM 2010




Inhibition
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