fMRI Methods That Have Not Caught On

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Section on Functional Imaging Methods

Laboratory of Brain and Cognition

http://fim.nimh.nih.gov

&

Functional MRI Facility

http://fmrif.nimh.nih.gov

Acquisition:

- Spiral Scanning
- Multi-Shot Spiral
- Multi-shot EPI
- Keyhole Imaging
- Partial k-space
- Echo-volume imaging
- 3D EPI
- Zoomed EPI
- Multiband excitation
- Low flip angle

Contrast Weighting

- Spin-echo
- Asymmetric Spin-Echo
- Arterial Spin Labeling
- VASO
- Low b Diffusion Weighting
- High b Diffusion Weighting
- Neuronal Current Imaging
- Multi-echo acquisition
- MRI time series phase information
- Steady State Free Precession
- Manganese contrast

Processing:

- Gating and variable TR correction
- event-related optimizing for response characterization rather than mapping
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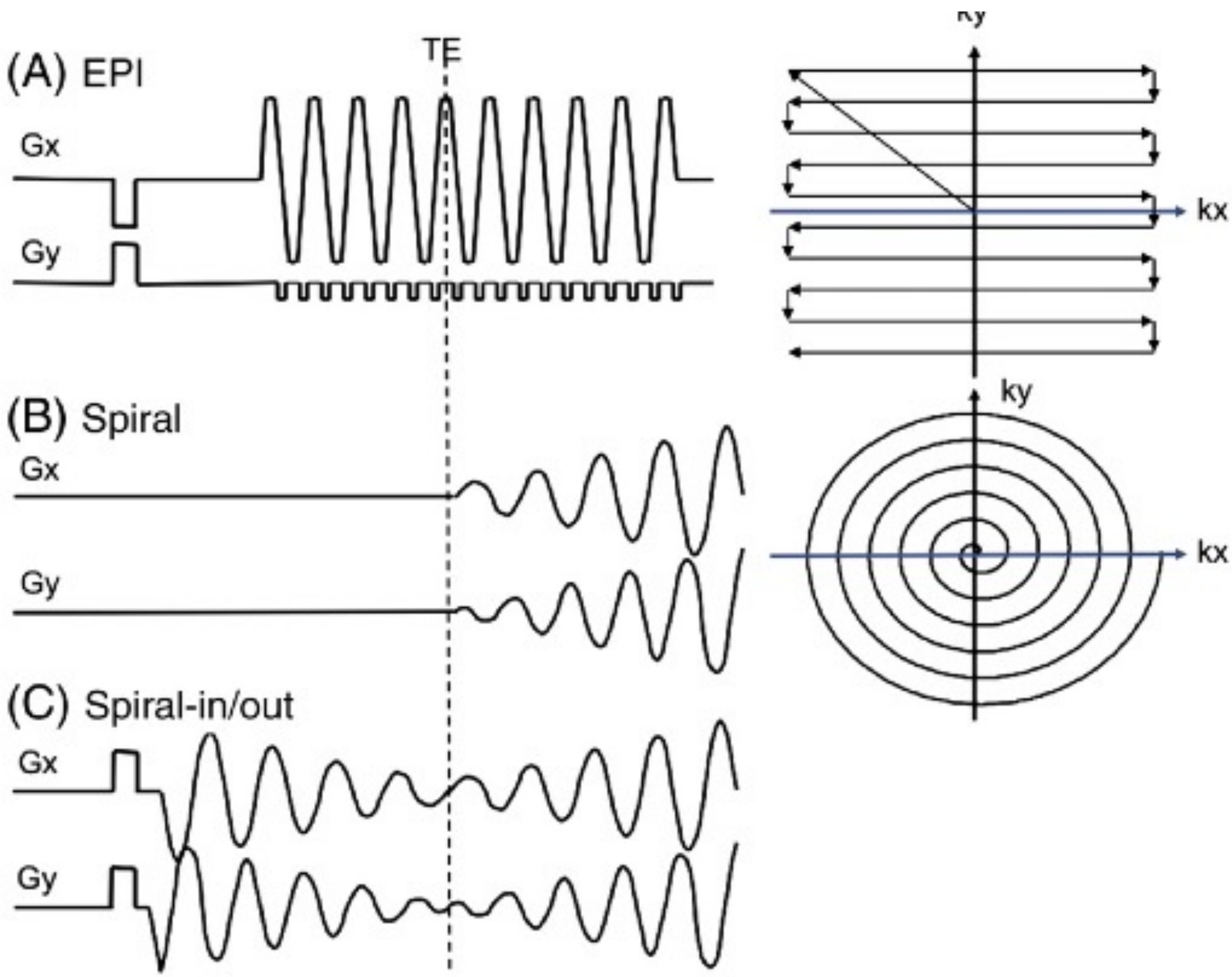
- latency mapping/modulation
- SE/GE ratios for localization
- large raw data databases

Spiral Scanning



G. Glover, NeuroImage 62, (2012) 706-12

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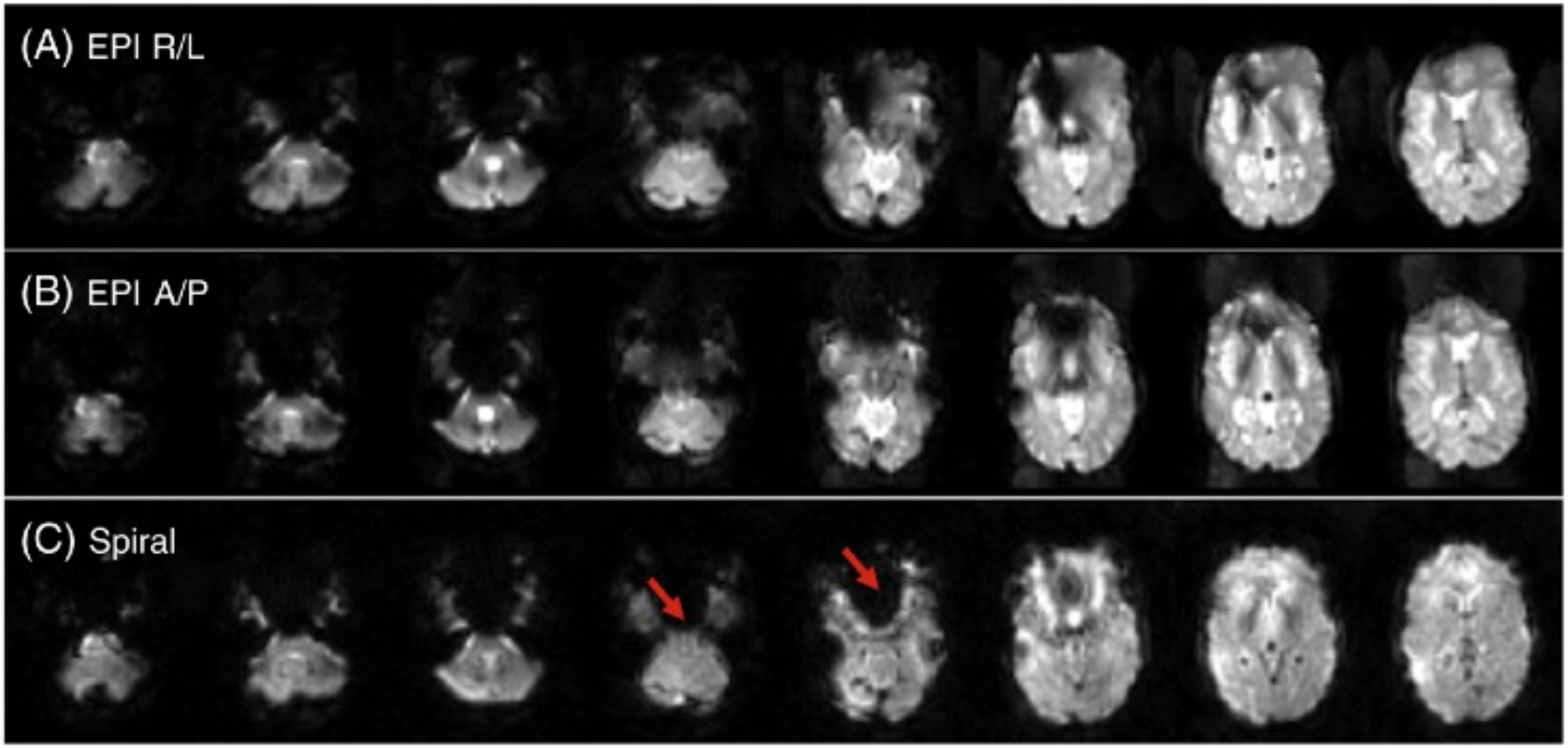
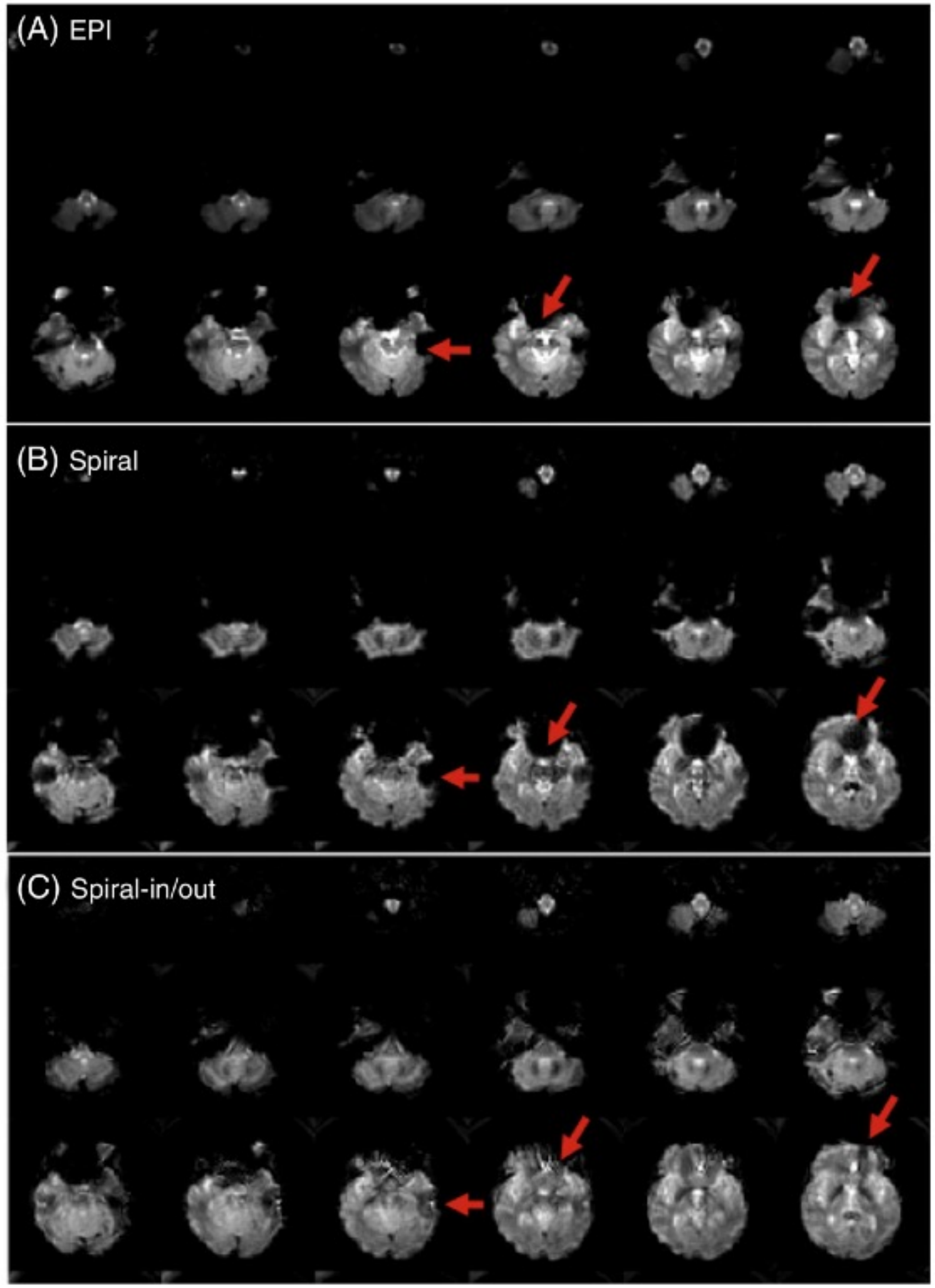


Fig. 3. EPI images with phase encoding direction R/L (A) or A/P (B). Susceptibility-induced field gradients (SFGs) cause geometric distortion along the phase encoding direction. With spiral (C), SFGs instead cause blurring. Note that there is increased signal in most slices with spiral, but loss in several slices (arrows).

G. Glover, NeuroImage 62, 706-12 (2012)

Spiral Scanning



G. Glover, NeuroImage 62, 706-12 (2012)

Spiral Scanning

Pros

- No distortion
- Minimal motion sensitivity
- Efficient

Cons

- Blurring
- Pulsation effects are ripples
  (not lines as with EPI)
- Reconstruction requires regridding – slower.

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Multi-Shot Spiral

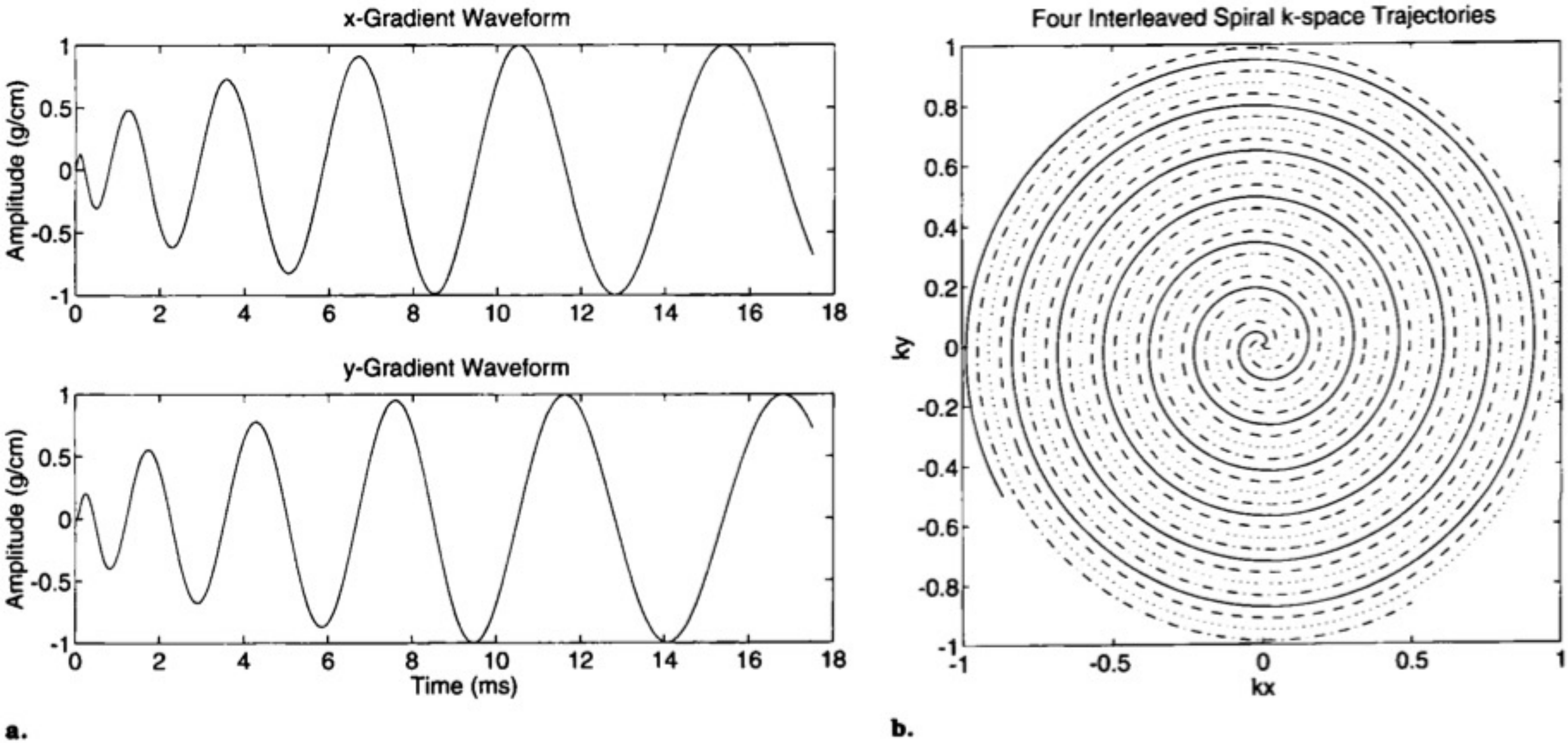
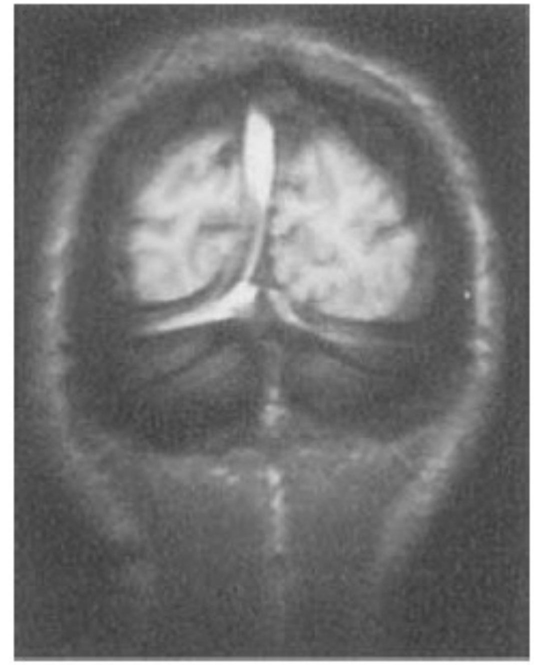


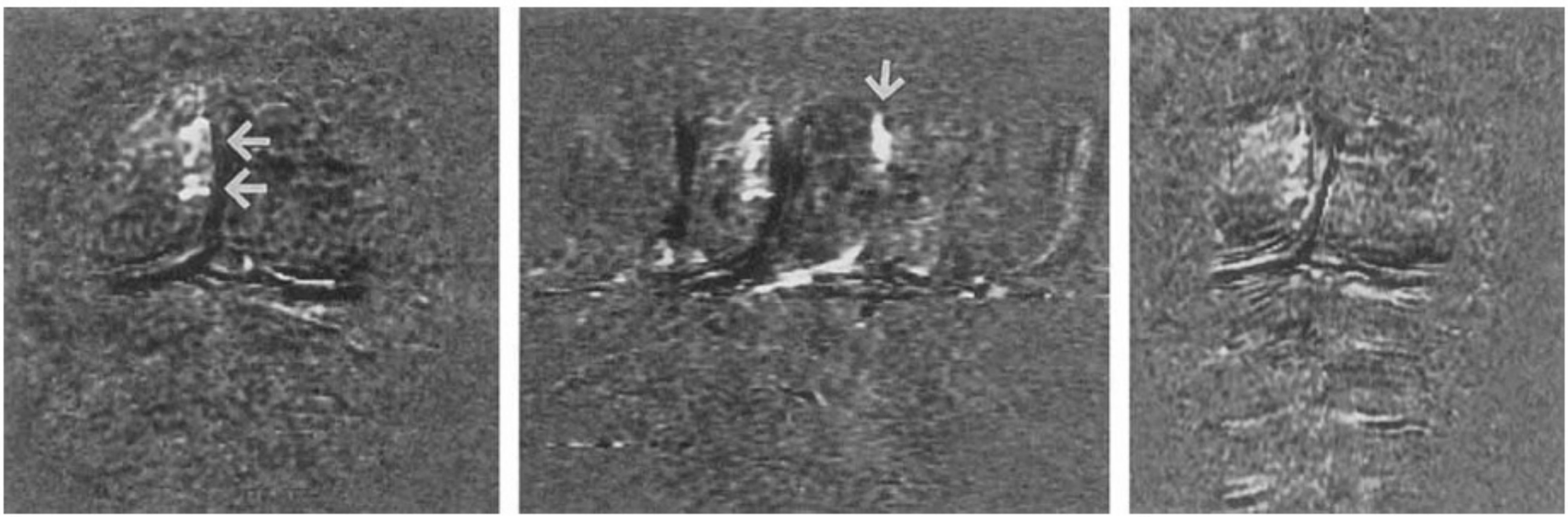
Figure 2. **(a)** Numerically designed gradient waveforms for spiral k-space trajectories and **(b)** four interleaved trajectories generated with these gradients.

D. Noll et al, JRMI 5:49-56 (1995)

Figure 3. Activation in primary visual cortex with a single character in the visual field. **(a)** T1-weighted image of coronal section near occipital pole. **(b–d)** Average difference images obtained with **(b)** spiral k-space acquisition, **(c)** 2DFT with left-to-right phase encoding, and **(d)** 2DFT with superoinferior phase encoding. Ghosted images of the sagittal sinus are seen in **c** (arrow). The Table lists measurements of the area and degree of activation of the two regions of activation indicated by the arrows in **b.**

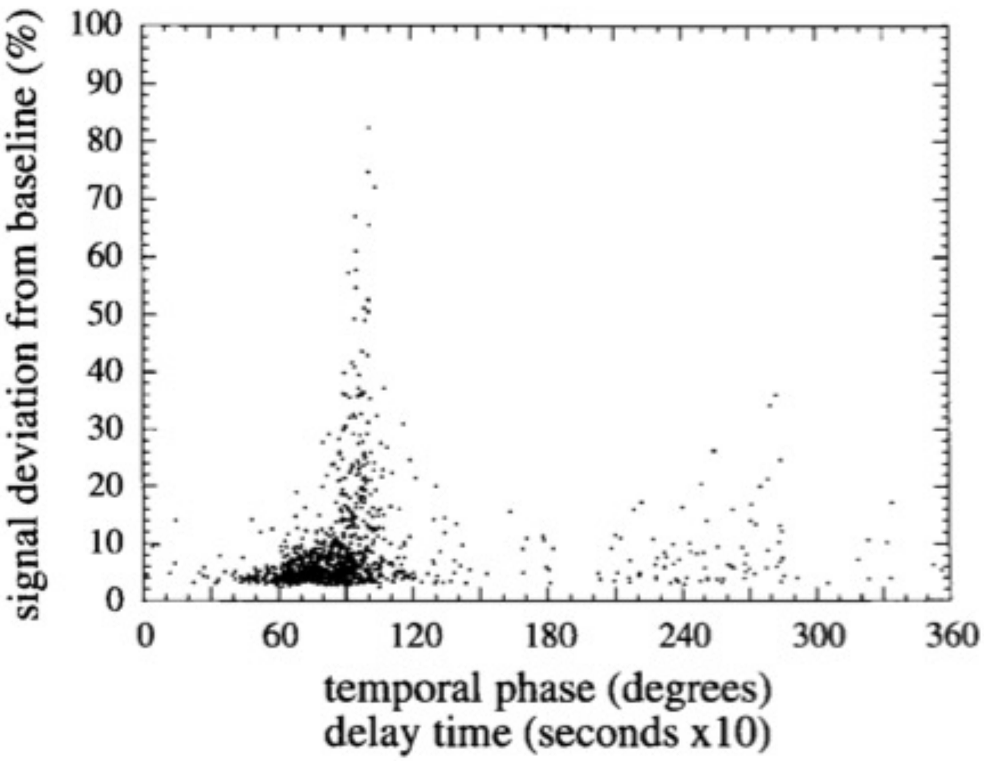


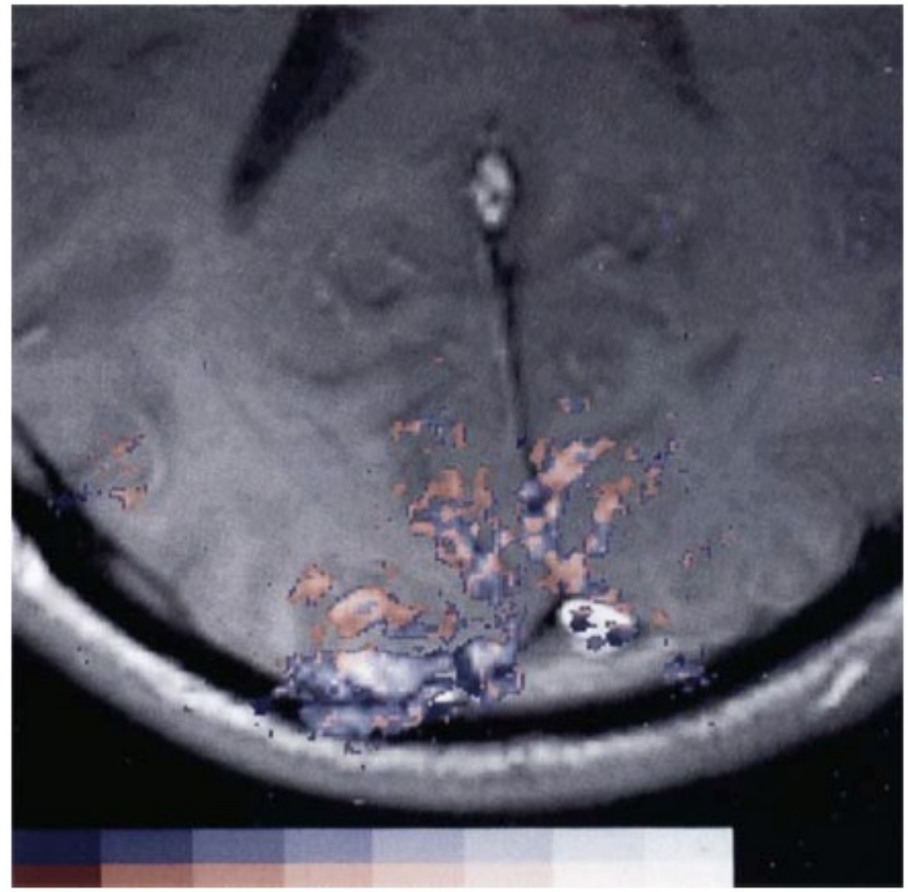
a.



b. **c.** **d.**

Multi-Shot Spiral – latency mapping





A. Lee et al, MRM 33, 745-754 (1995)

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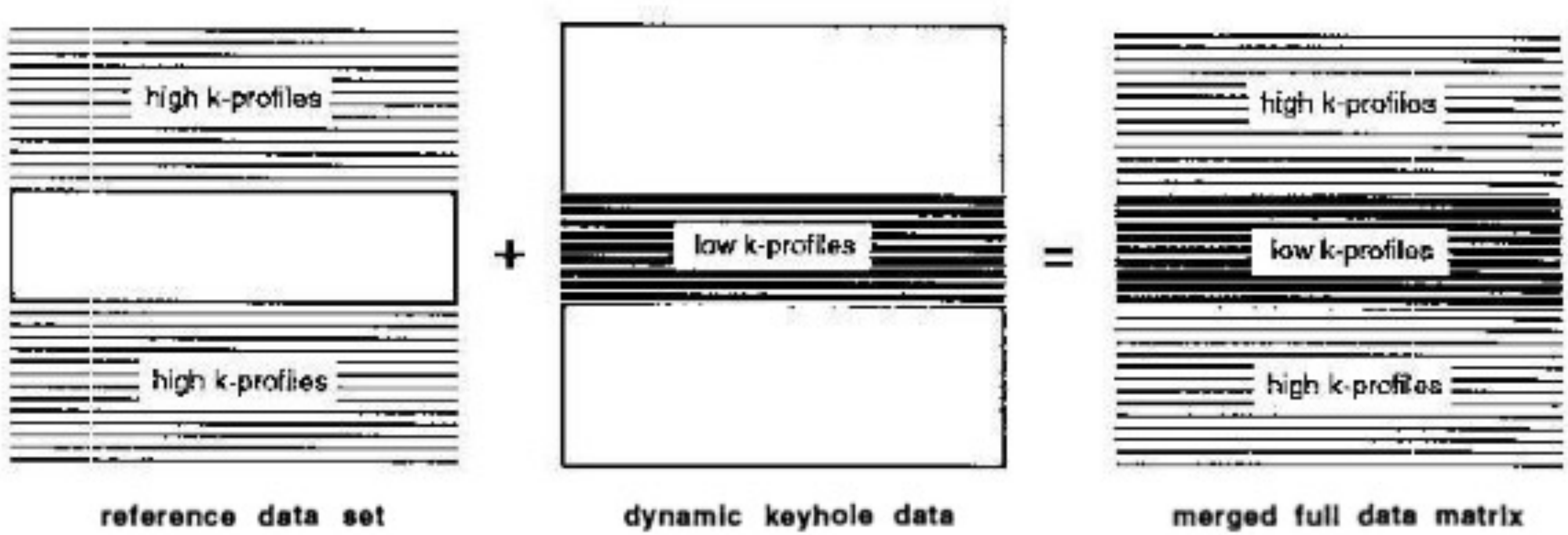
Keyhole imaging



van Vaals et al. JMRI, 3, 671-675 (1993)

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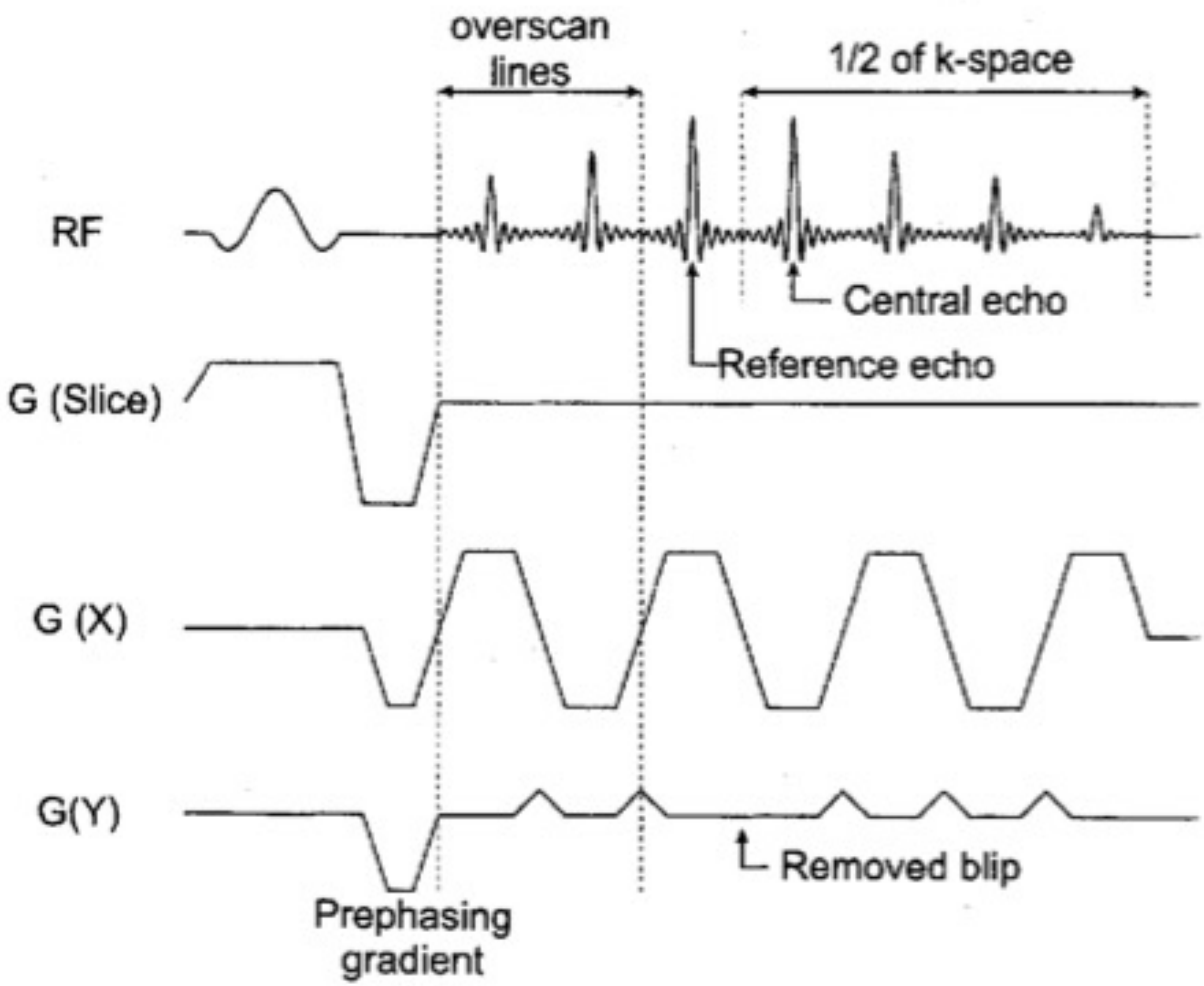
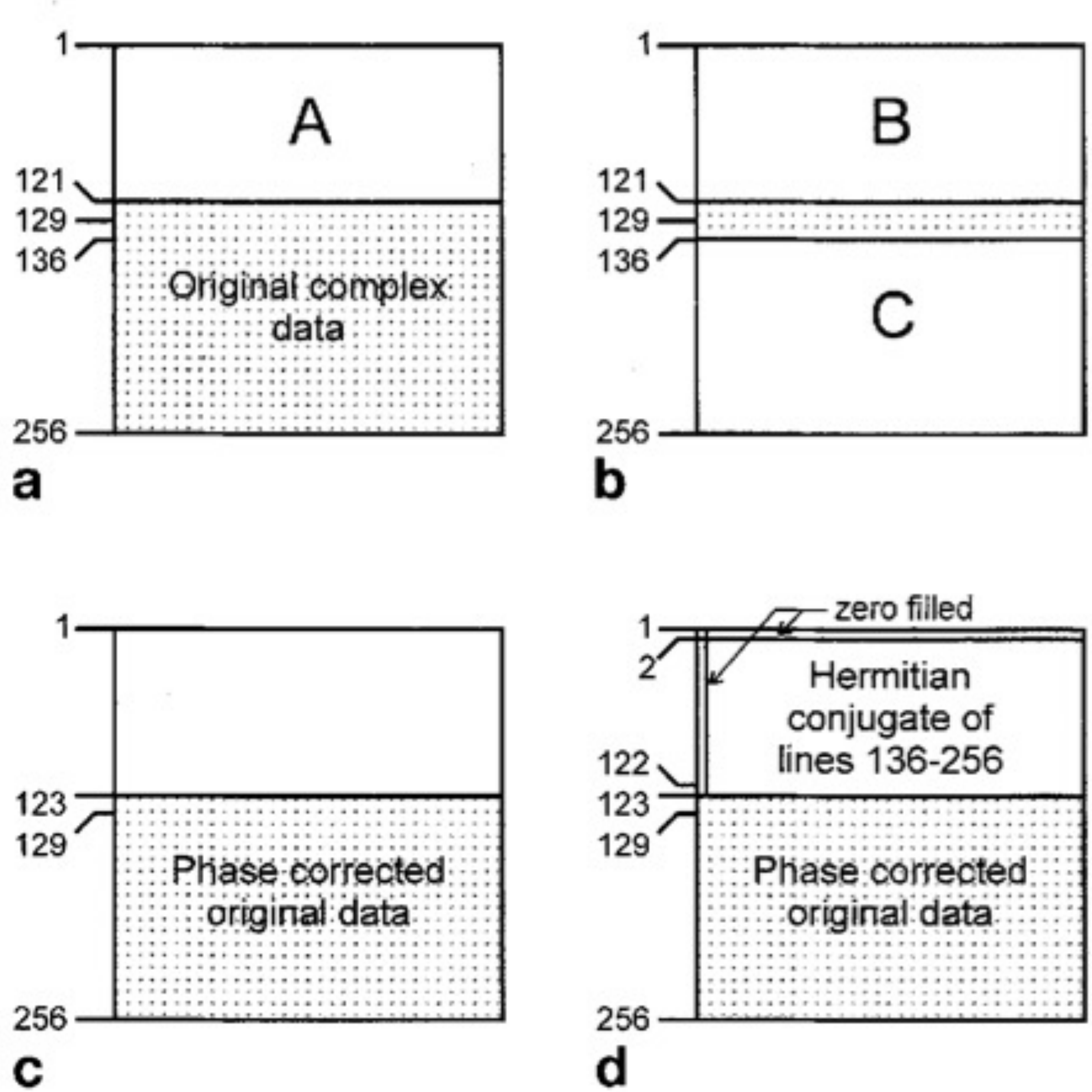
Partial k-space reconstruction



A. Jesmanowicz et al, MRM 40, 754-762 (1998)

Partial k-space reconstruction



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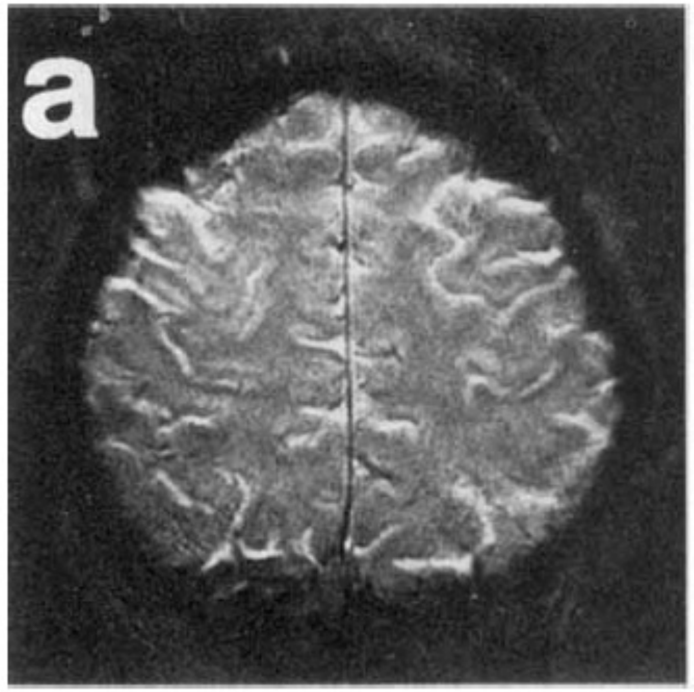

Echo and Readout Times (ms)

Resolution	TE		Readout time	
	Full *k*-space	Half *k*-space	Full *k*-space	Half *k*-space
64 × 64	23.0	9.2	37.4	23.6
128 × 128	66.4	12.6	123.8	70.1
192 × 192	134.4	16.1	259.4	141.1
256 × 256	226.9	19.5	444.1	236.7

A. Jesmanowicz et al, MRM 40, 754-762 (1998)

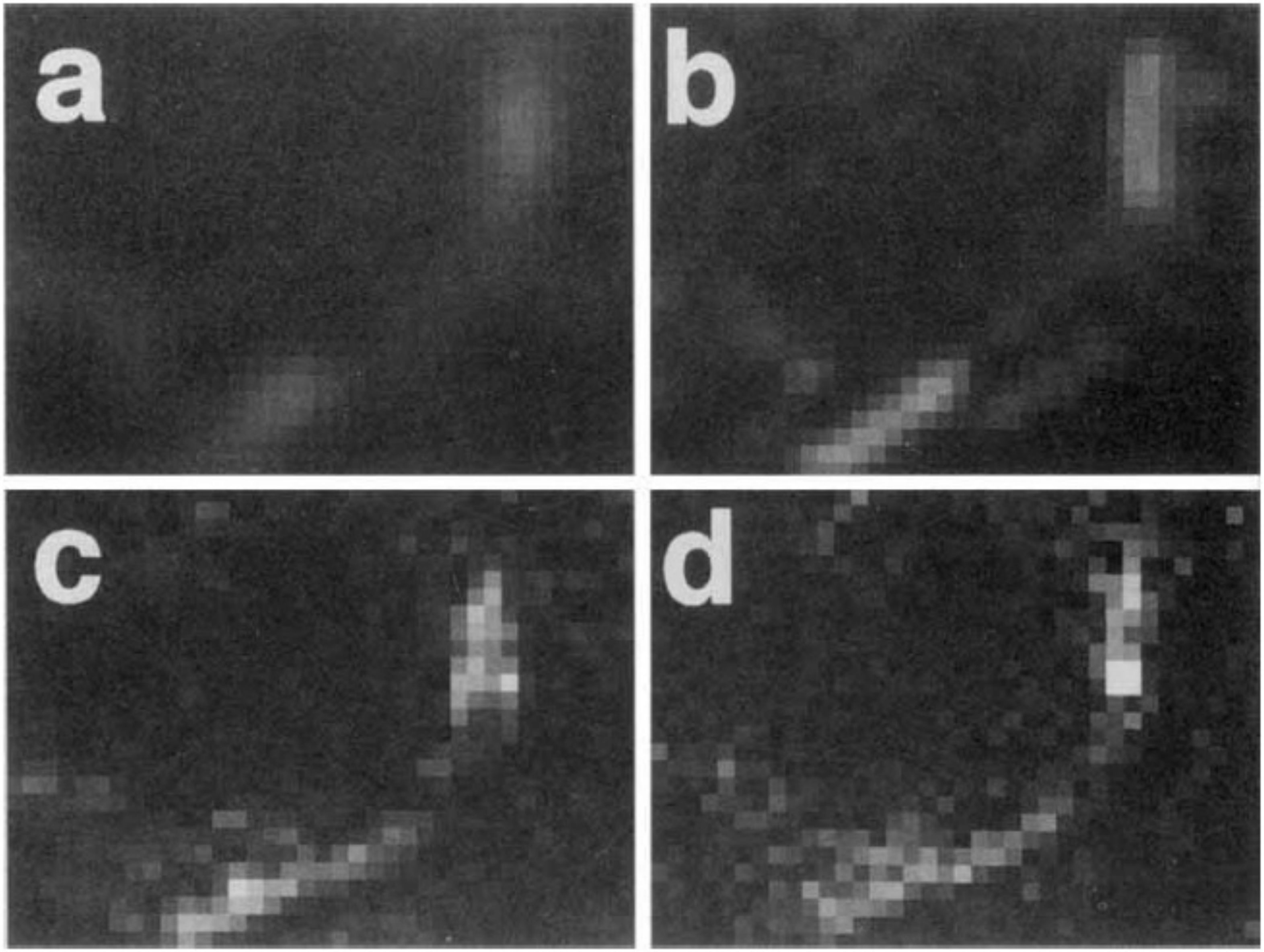

FIG. 9. Percent change maps of the right motor cortex. Slice width was 5 mm, and the FOV was 16 cm. Image matrix sizes and corresponding voxel sizes were: (a) 64 × 64 and 2.5 mm^2; (b) 128 × 128 and 1.25 mm^2; (c) 192 × 192 and 0.83 mm^2; (d) 256 × 256 and 0.62 mm^2. TE was 20 ms for each image, and the bandwidth was 166.6 kHz. Partial *k*-space acquisition and conjugate synthesis reconstruction were used for all time series. TR = 1 s. Each time series consisted of 120 images. The bilateral finger-tapping paradigm was 30 s off, 20 s on, 20 s off, 20 s on, 30 s off. All the images were reconstructed onto a 256 × 256 matrix.

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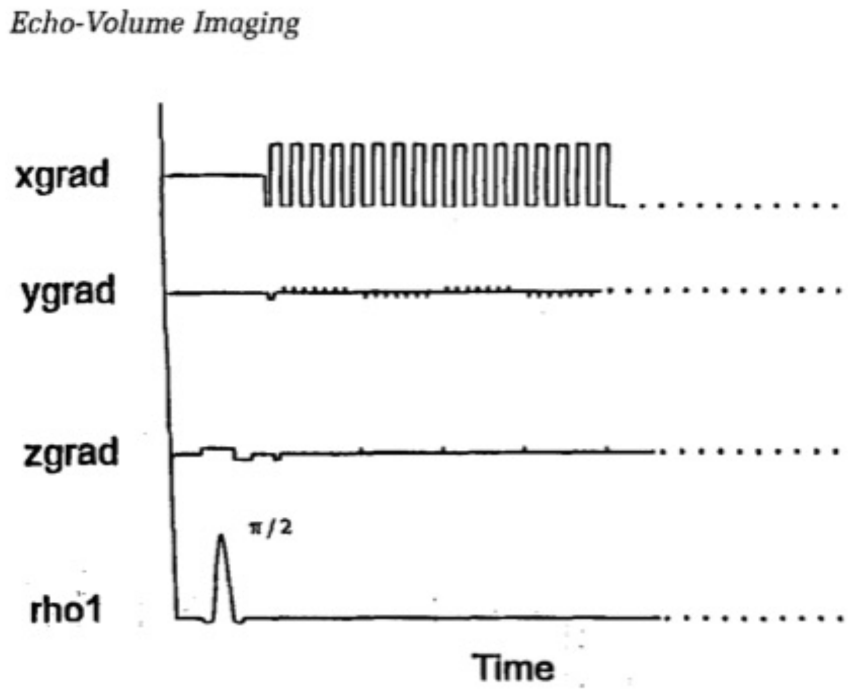
Echo Volume Imaging



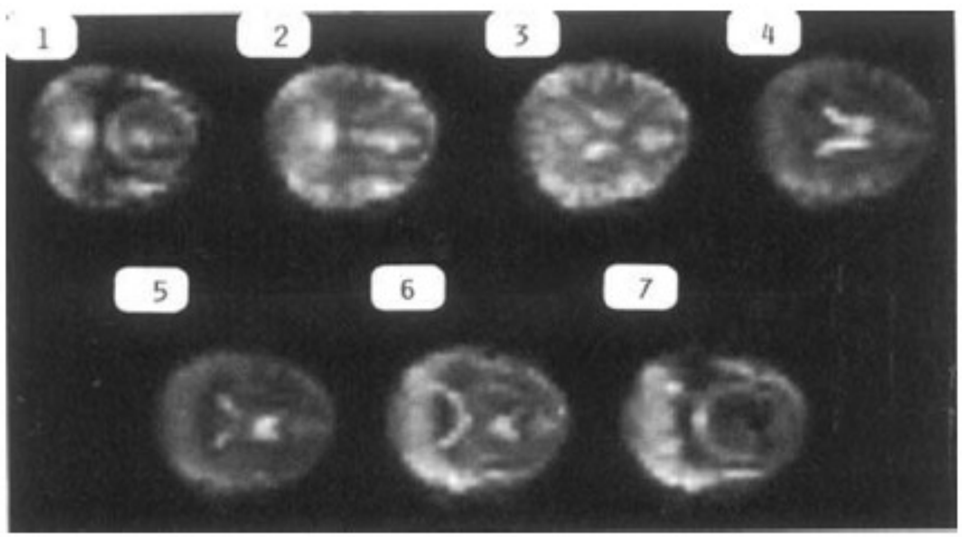


FIG. 3. Single-echo EVI human brain images. Images are taken with a FOV of 24 × 24 × 3.5 cm^3 and matrix of 32 × 32 × 7.

A. Song et al MRM, 32, 668-671 (1994)

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3D EPI

Pros: Shorter TR and higher SNR..

Cons: Physiologic noise..

Resolution	2D		3D	
	TR	AF	TR	AF
1.5 mm	5.96 s	2	3.07 s	2×2
2.0 mm	3.65 s	2	1.88 s	2×2
2.5 mm	2.70 s	2	1.38 s	2×2
3.0 mm	2.10 s	2	1.07 s	2×2

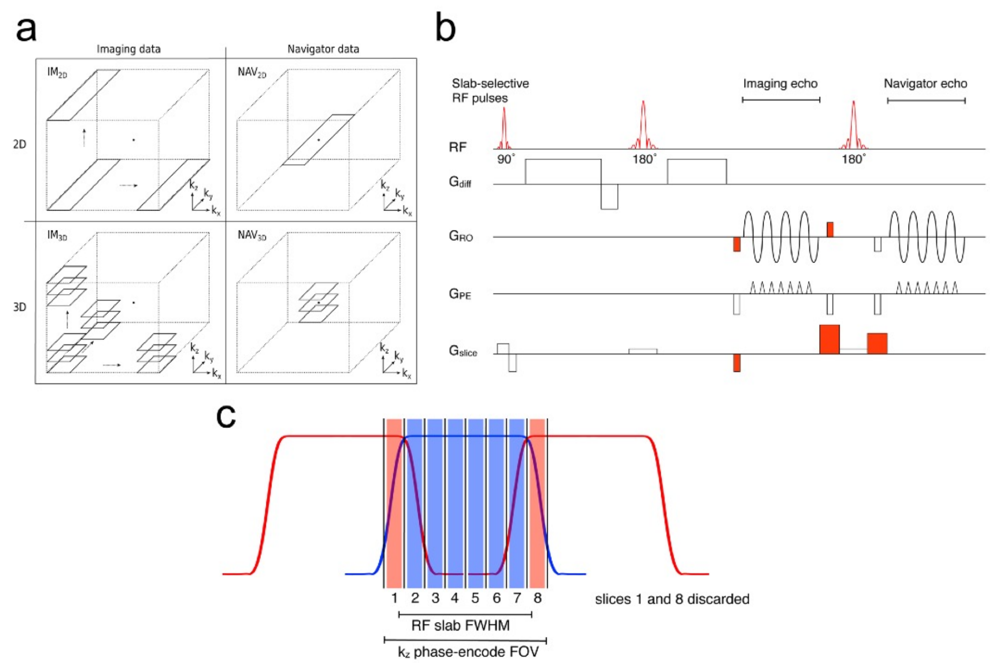

FIG. 1. **a:** Illustration of 2D and 3D k-space acquisition schemes in a 3D version of rs-EPI. In each of the four panels, the dotted line represents the boundaries of the complete k-space matrix and the dot signifies the center of 3D k-space. Solid lines represent acquisitions of one shot of k-space data. In the 2D versions (IM_{2D} and NAV_{2D}), these shots are simply k_z phase-encoded readout segments. In the 3D versions (IM_{3D} and NAV_{3D}), each shot is a stack of readout segments with reduced k_y extent, which is implemented in the pulse sequence by inserting G_z blip gradients to move to the next k_z plane and G_y rewind gradients to move to the k_y starting position. The low k_y resolution readout segments are contiguous in k_z. For the imaging data (IM_{2D} and IM_{3D}), prephasing is used to move these shots around to sample the whole 3D k-space matrix. The navigator always acquires a full k_y resolution readout segment (NAV_{2D}) or stack of low k_y resolution readout segments (NAV_{3D}) at the center of 3D k-space. **b:** IM_{2D}+NAV_{2D} 3D rs-EPI pulse sequence with modifications to the original rs-EPI sequence colored red. Slab-selective RF pulses were used and k_z phase-encoding was added. The k-space shot was determined based on the position in the cardiac cycle so the k_x and k_z pre- and re-phasing gradients were updated in real-time. **c:** Illustration with eight k_z phase-encodes how adjacent slabs were overlapped and slices at either end of the slab were discarded. Also, the k_z phase-encode FOV was oversampled to be larger than the slab profile defined by the full width at half maximum (FWHM) of the RF pulse. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

R. Frost, et al. MRM, in press

B. A. Poser, et al. NeuroImage, 51, 261-266 (2010)

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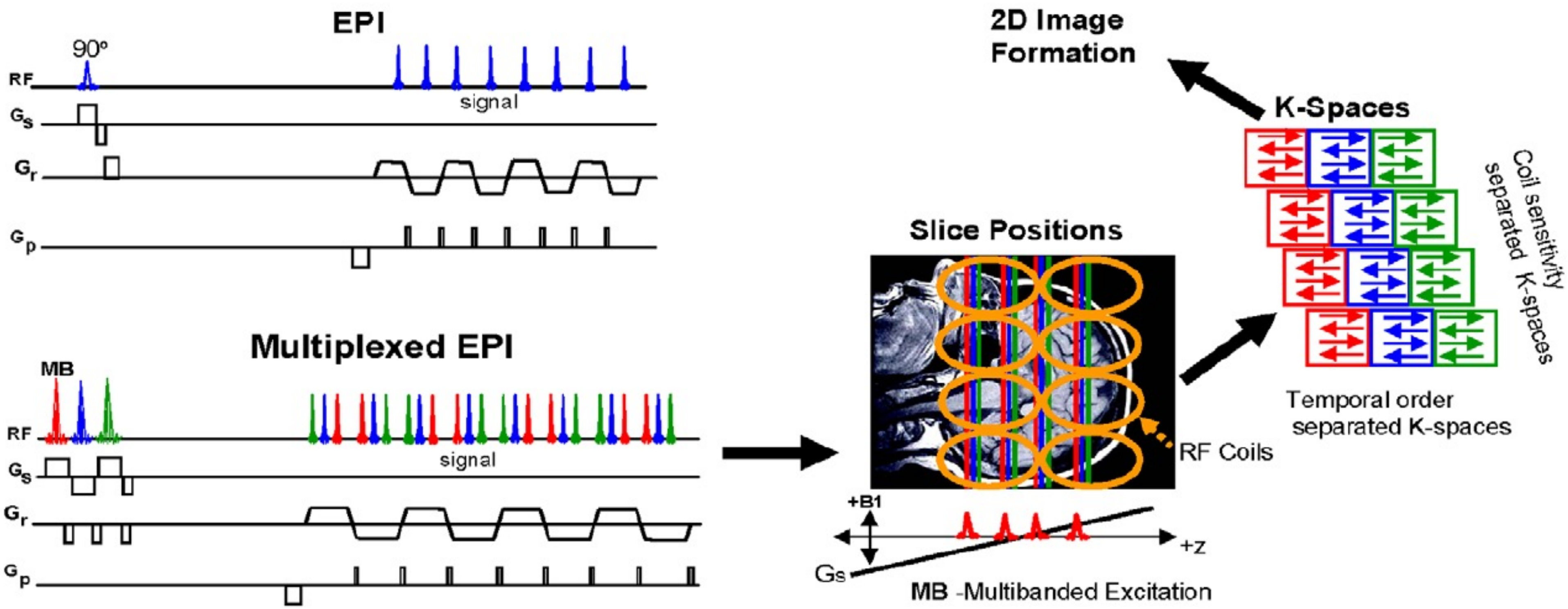
Multiband Excitation



Feinberg et al, PLoS one, 5, 12, e15710 (2010)

D. A. Feinberg and K. Setsompop, JMR, 229, 90-100, (2013)

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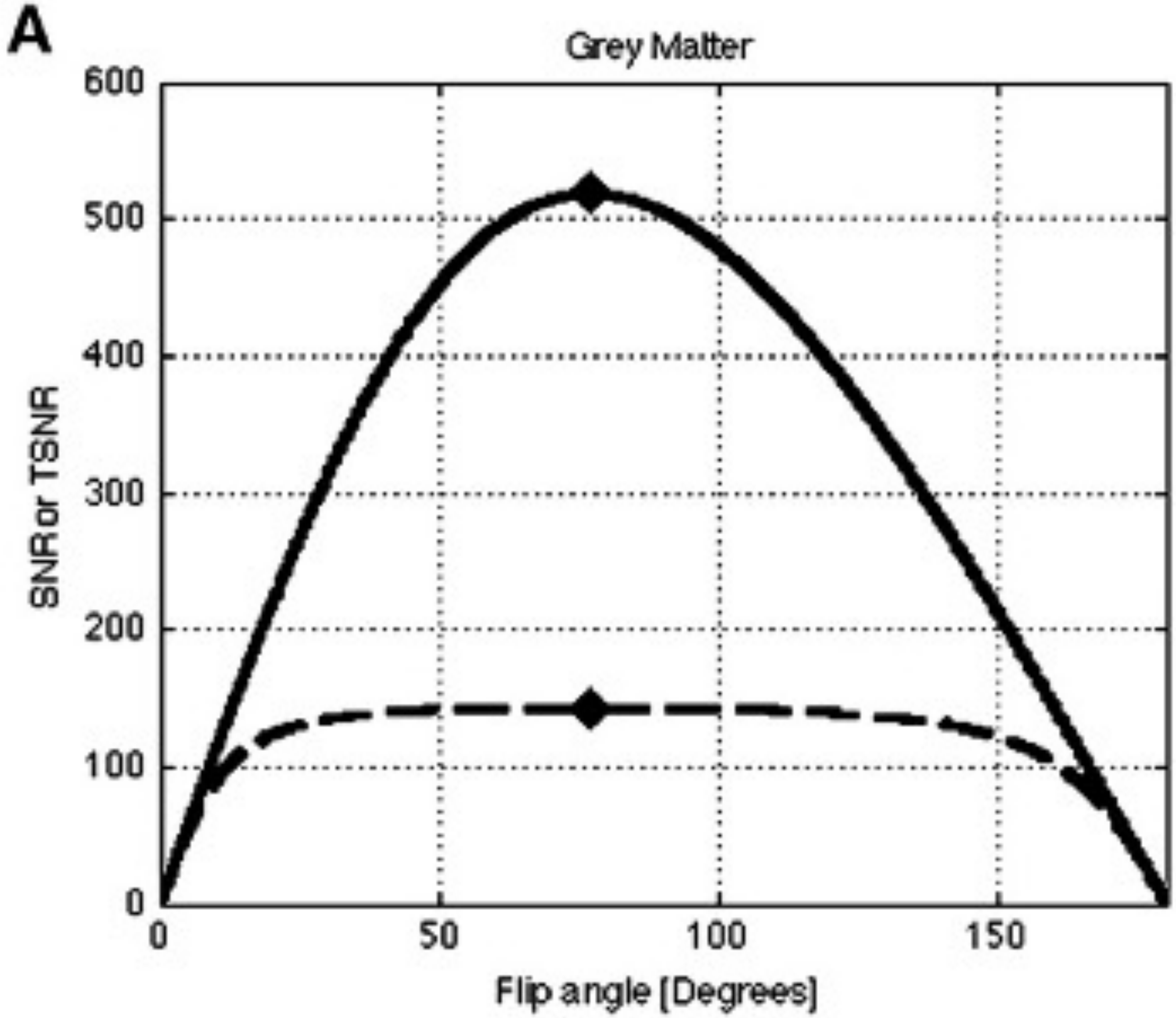
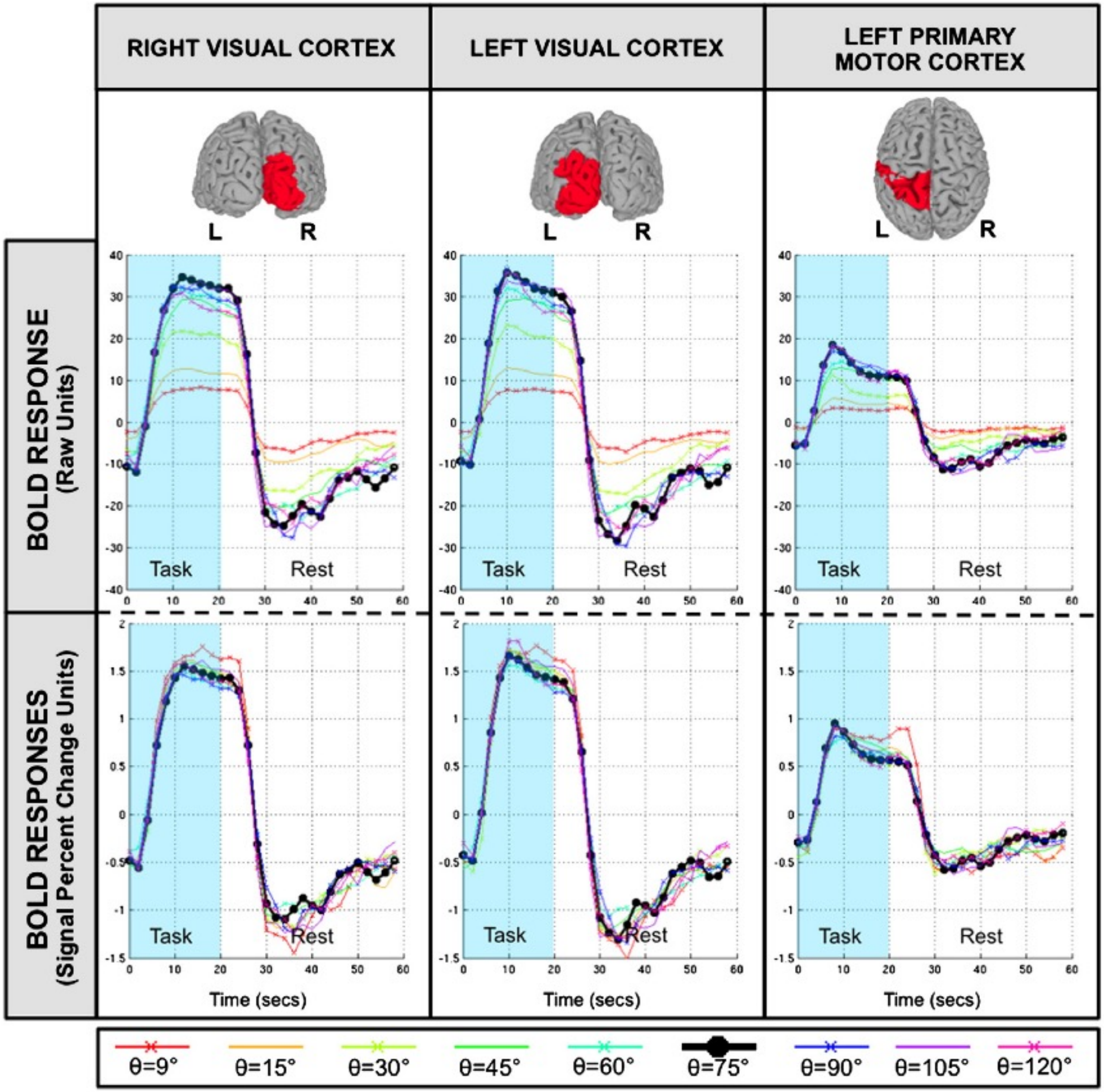
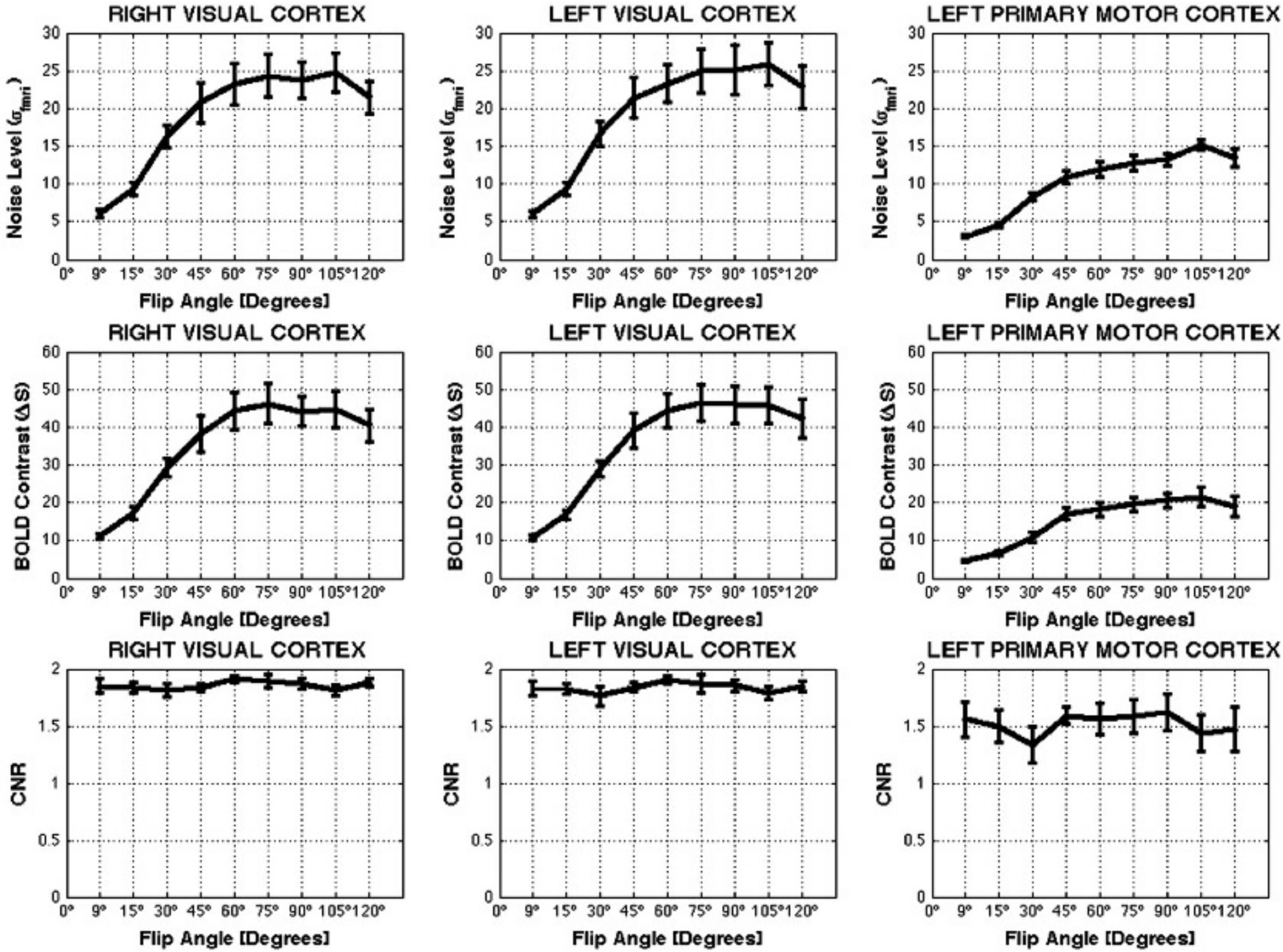
Low flip angle



J. Gonzalez-Castillo, et al., NeuroImage, 54, 2764-2778 (2011)



RIGHT VISUAL CORTEX
LEFT VISUAL CORTEX
LEFT PRIMARY MOTOR CORTEX
L
R
BOLD RESPONSE (Raw Units)
BOLD RESPONSES (Signal Percent Change Units)
Task
Rest
Time (secs)
θ=9°
θ=15°
θ=30°
θ=45°
θ=60°
θ=75°
θ=90°
θ=105°
θ=120°


RIGHT VISUAL CORTEX
LEFT VISUAL CORTEX
LEFT PRIMARY MOTOR CORTEX
Noise Level (σ_{fmri})
BOLD Contrast (ΔS)
CNR
0° 9° 15° 30° 45° 60° 75° 90° 105° 120°
Flip Angle [Degrees]

Pros:
reduced inflow
better slice profile
higher anatomical contrast for registration

Cons:
Only works when physiologic noise dominates
Resting state seems to have less clear advantages

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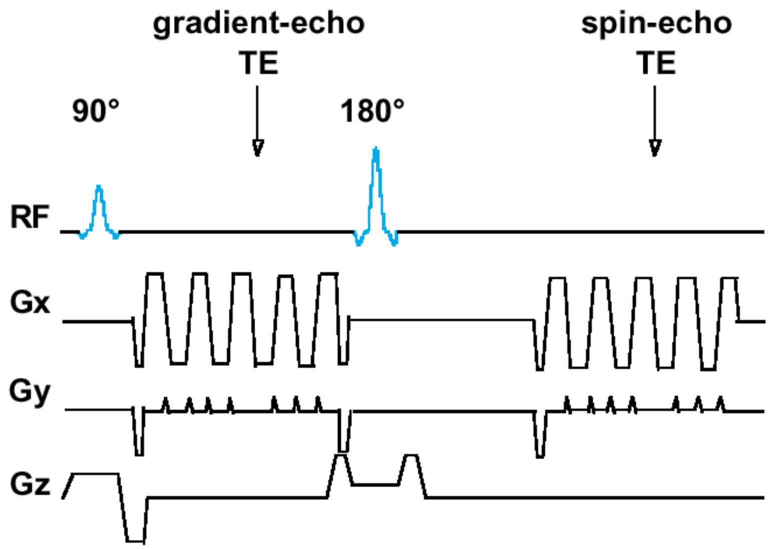
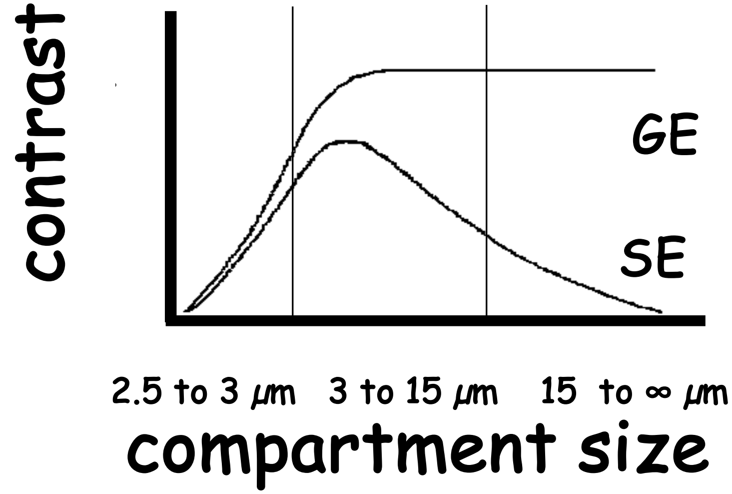
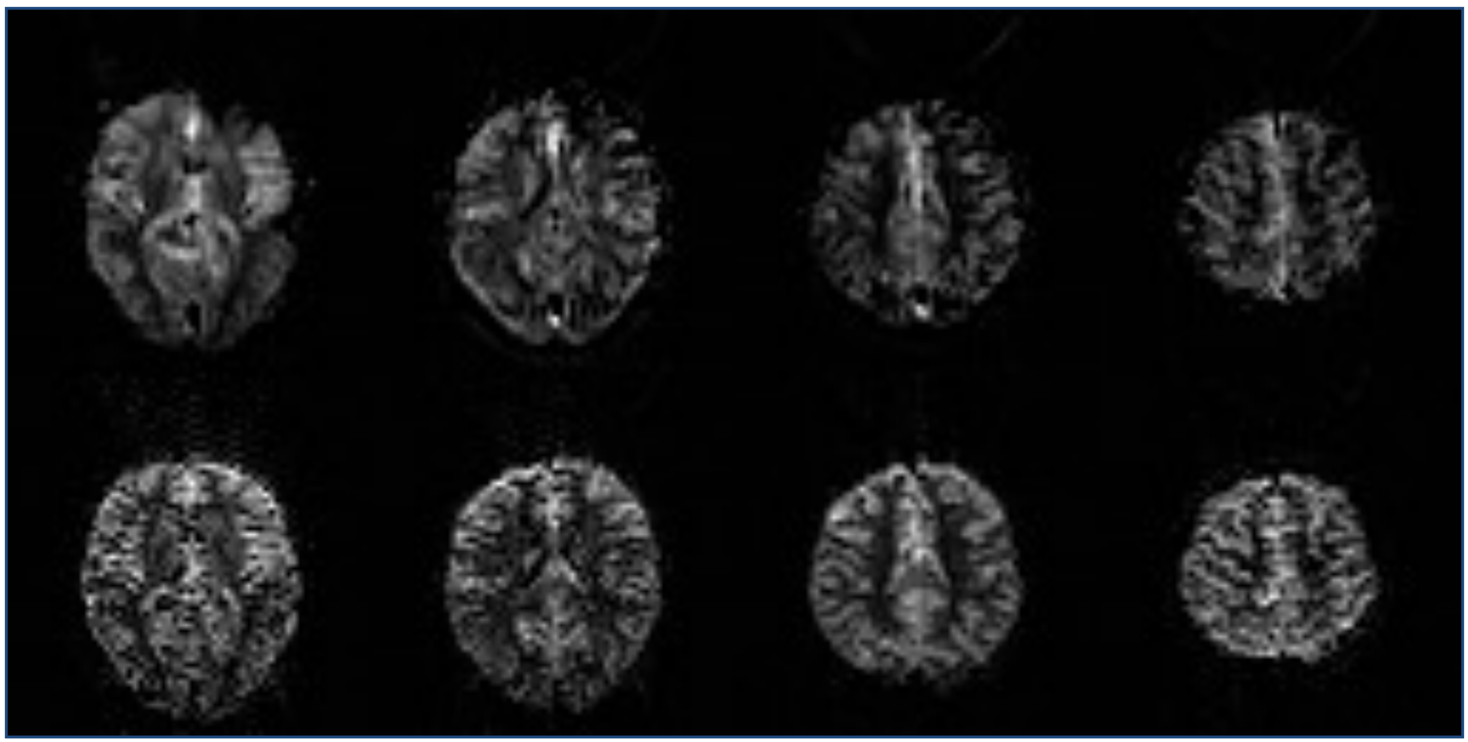
Spin-echo



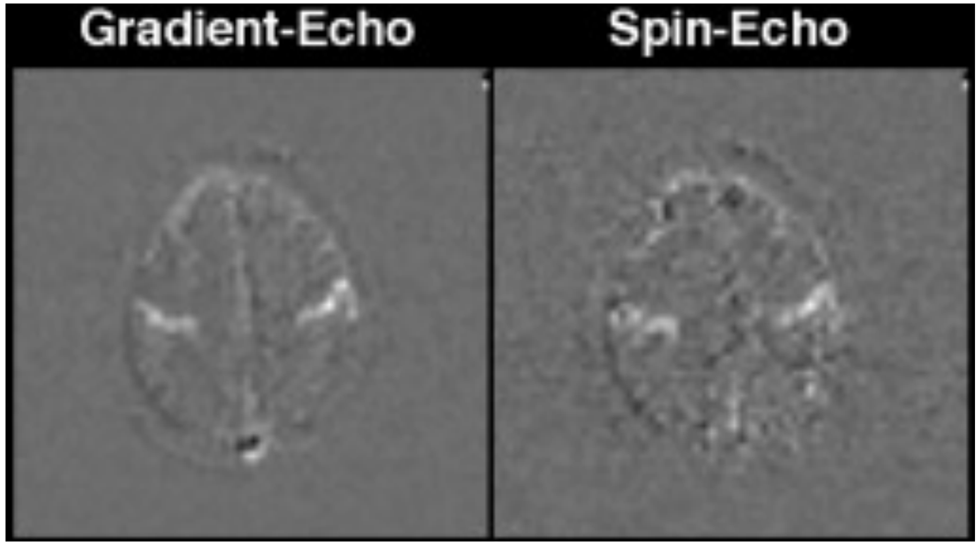


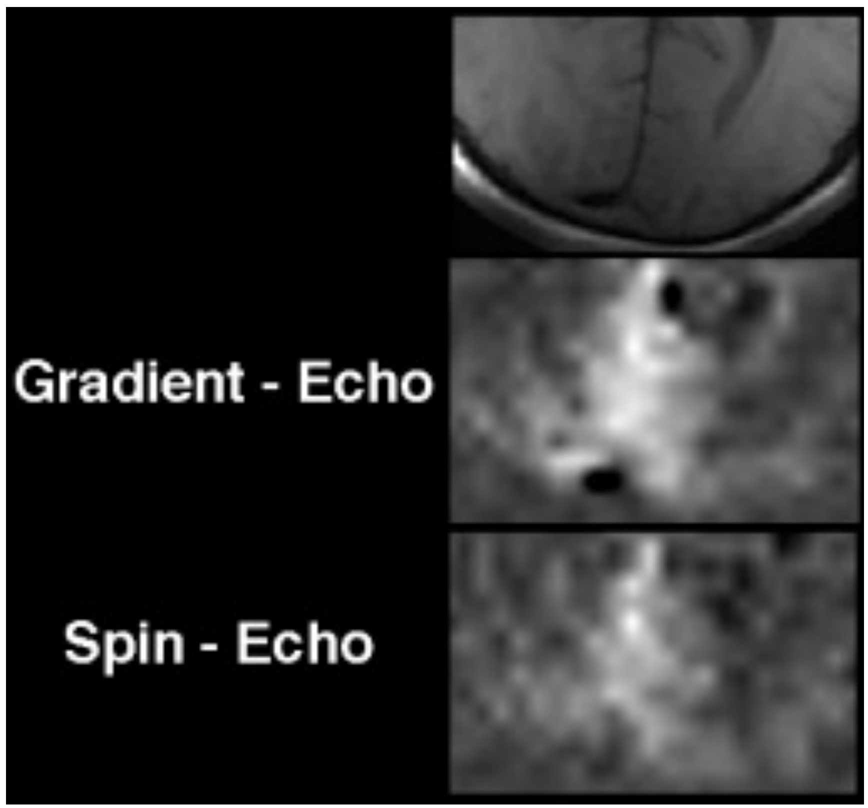
GE
TE = 30 ms

SE
TE = 110 ms



Spin-echo





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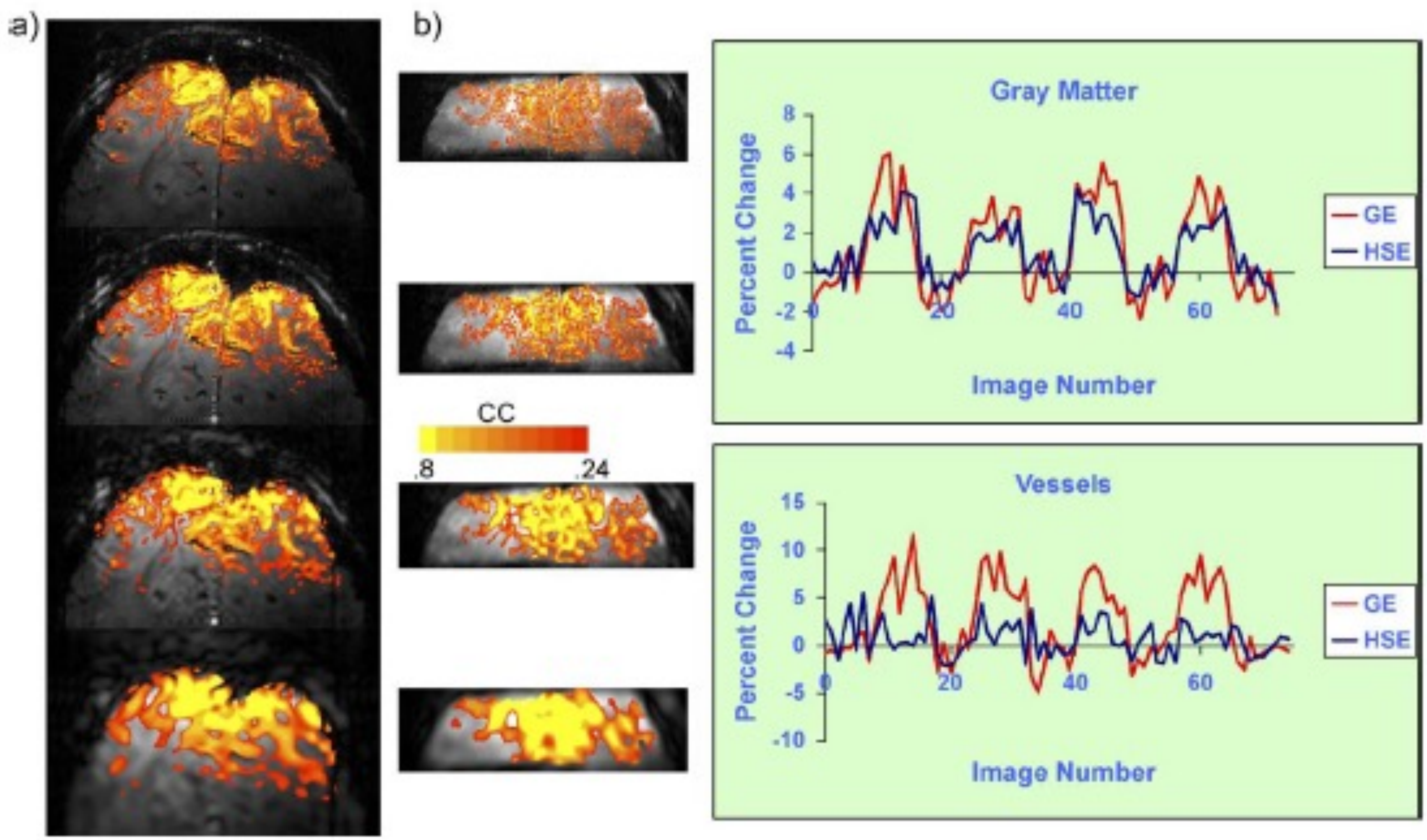
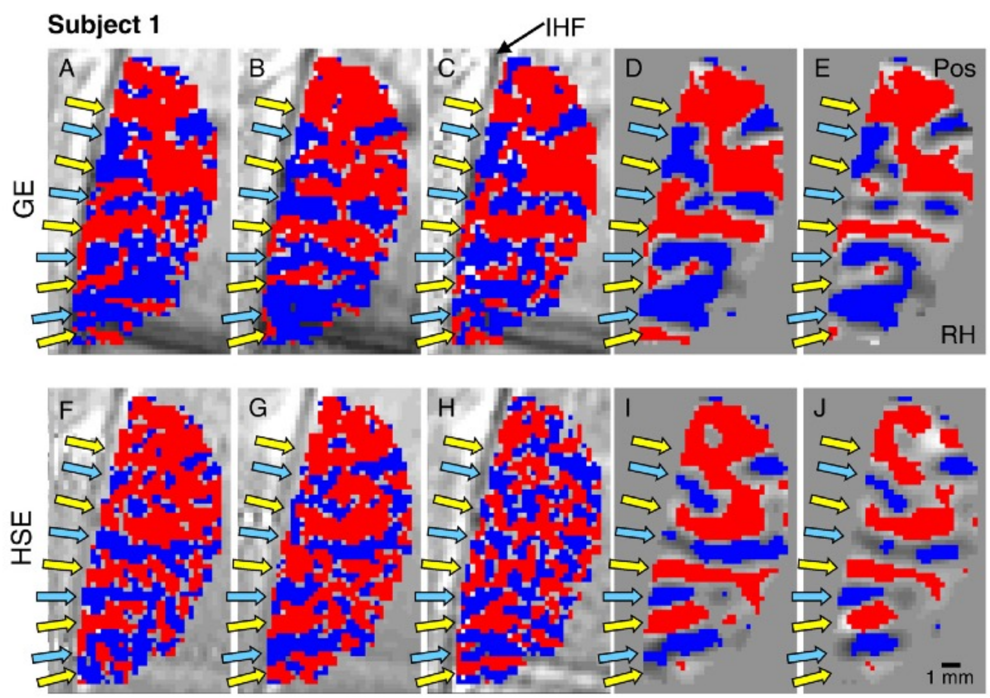
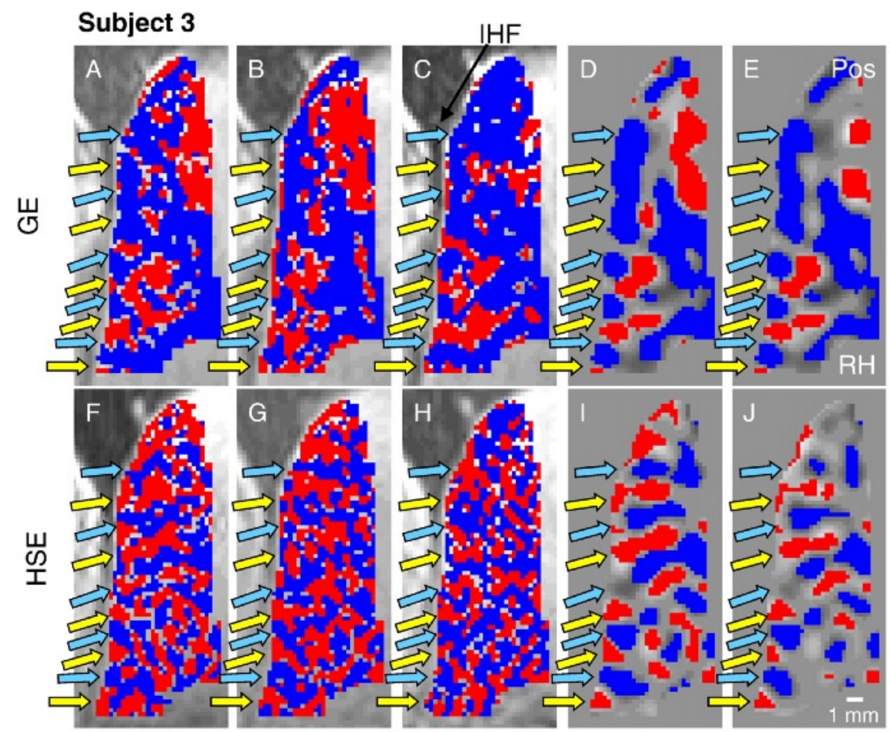


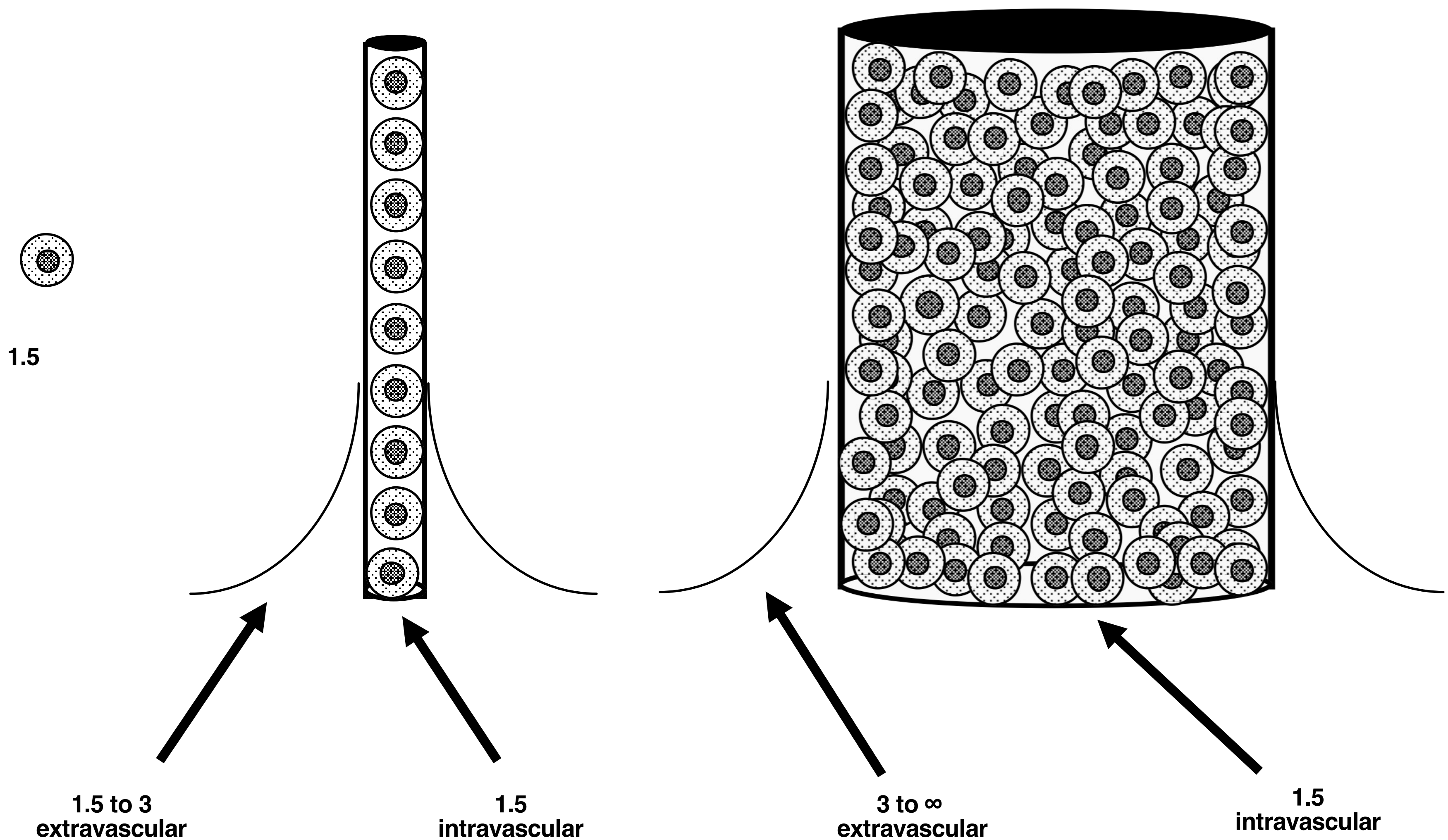
Yacoub et al. NeuroImage 24 (3), pp. 738-750

Spin-echo





E. Yacoub, NeuroImage 37, 1161 – 1177 (2007)



1.5
1.5 to 3
extravascular
1.5
intravascular
3 to ∞
extravascular
1.5
intravascular

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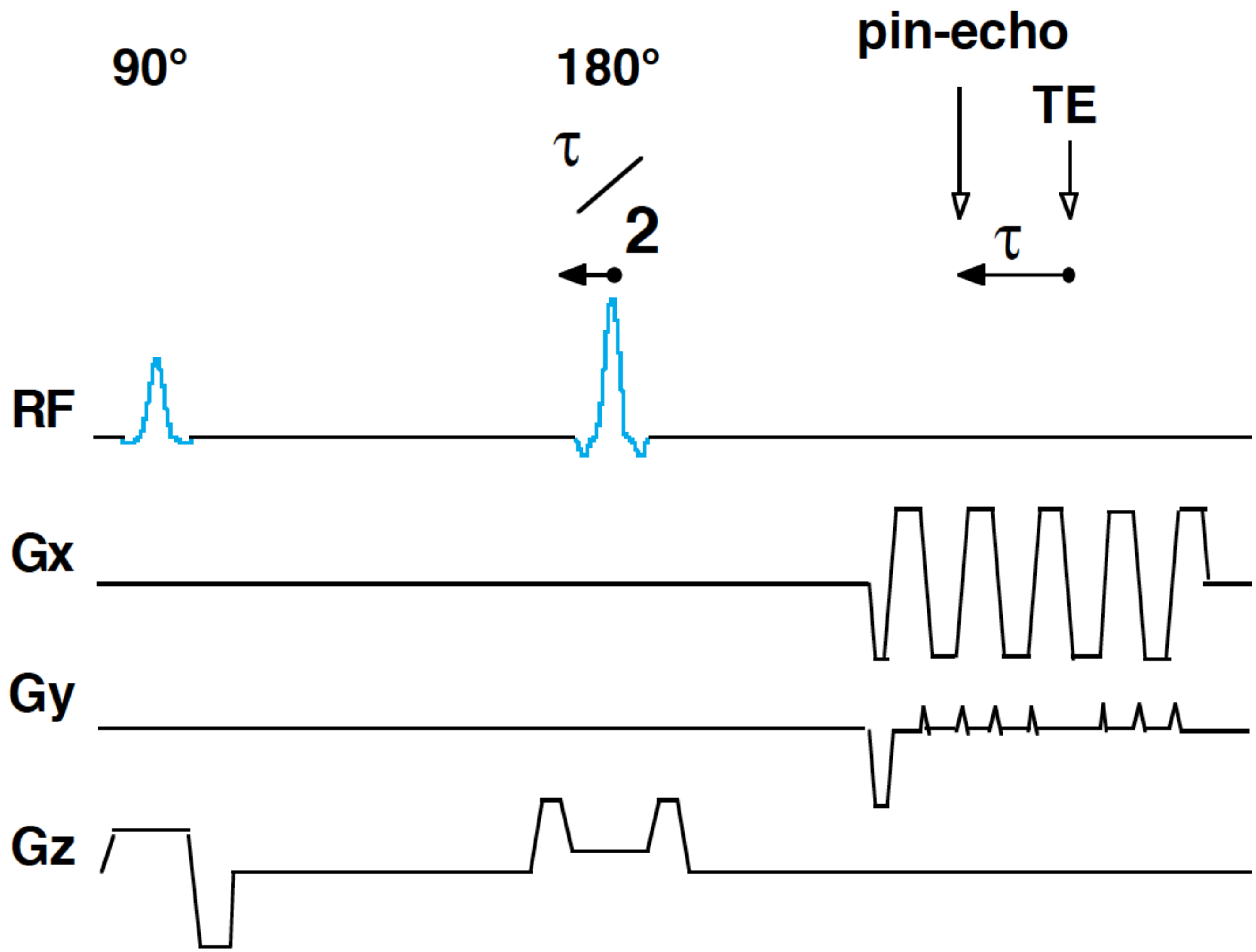
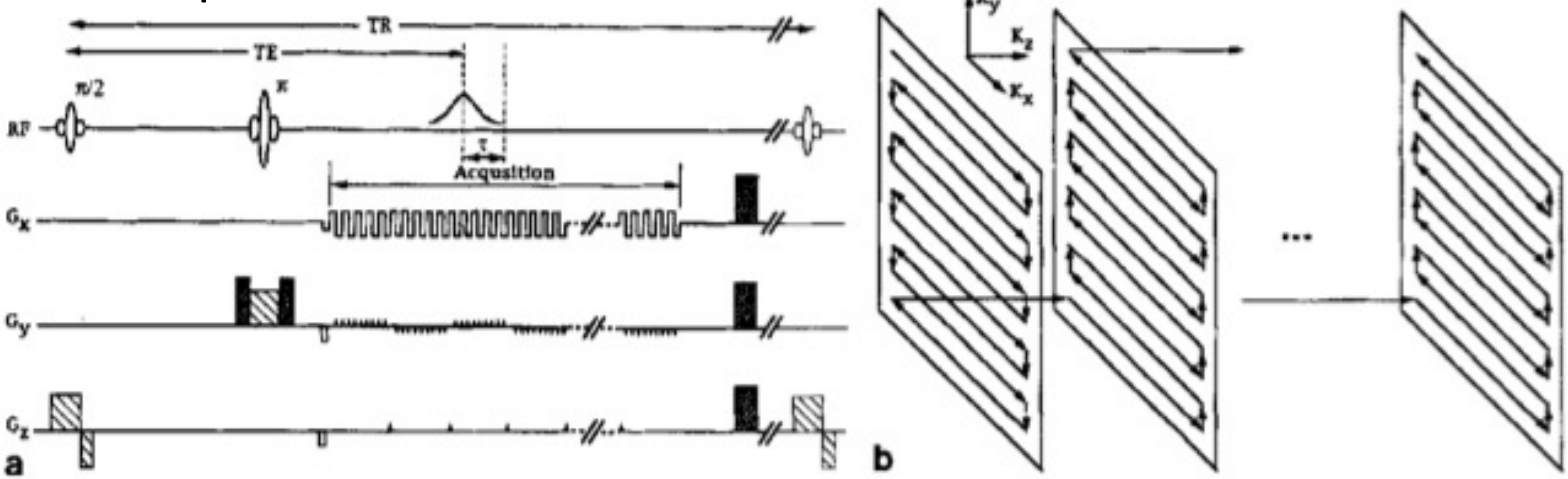
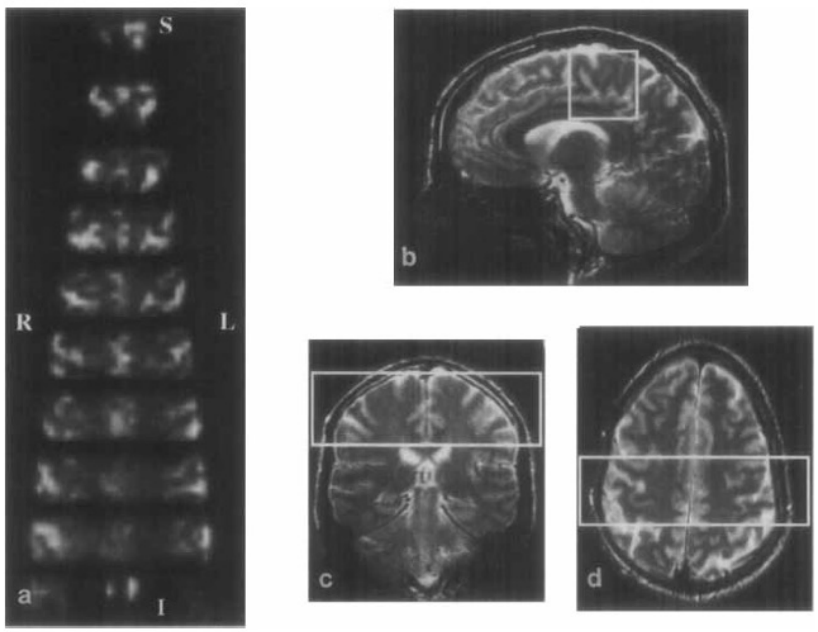
Assymetric Spin-echo



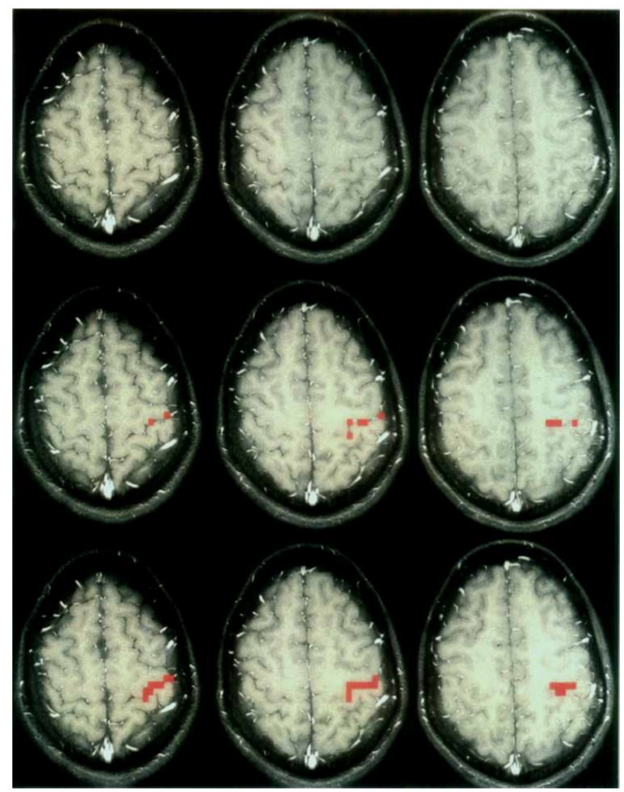
Assymetric Spin-echo & 3D EPI





SE

ASE



Yang et al, JMRI, 7, 371-375, (1997)

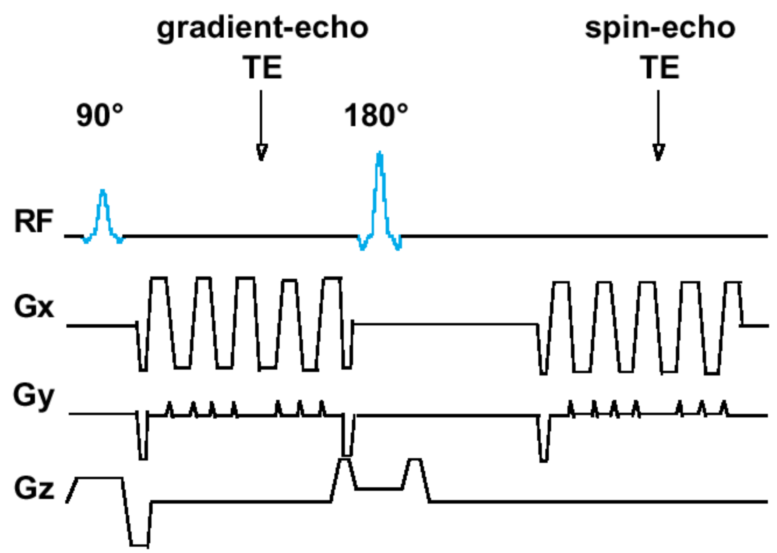
Assymetric Spin-echo

Pros:

- The 180 pulse does not refocus rapidly flowing spins (reduces noise)
- T2* weighting lower limit is not limited by readout window width
- Can add a gradient-echo EPI readout in first part of sequence.

Cons:

- Takes about 60 ms longer, so reduces number of slices per TR.



Acquisition:

- Spiral Scanning
- Multi-Shot Spiral
- Multi-shot EPI
- Keyhole Imaging
- Partial k-space
- Echo-volume imaging
- 3D EPI
- Zoomed EPI
- Multiband excitation
- Low flip angle

Contrast Weighting

- Spin-echo
- Asymmetric Spin-Echo
- Arterial Spin Labeling
- VASO
- Low b Diffusion Weighting
- High b Diffusion Weighting
- Neuronal Current Imaging
- Multi-echo acquisition
- MRI time series phase information
- Steady State Free Precession
- Manganese contrast

Processing:

- Gating and variable TR correction
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- calibration or global stressors
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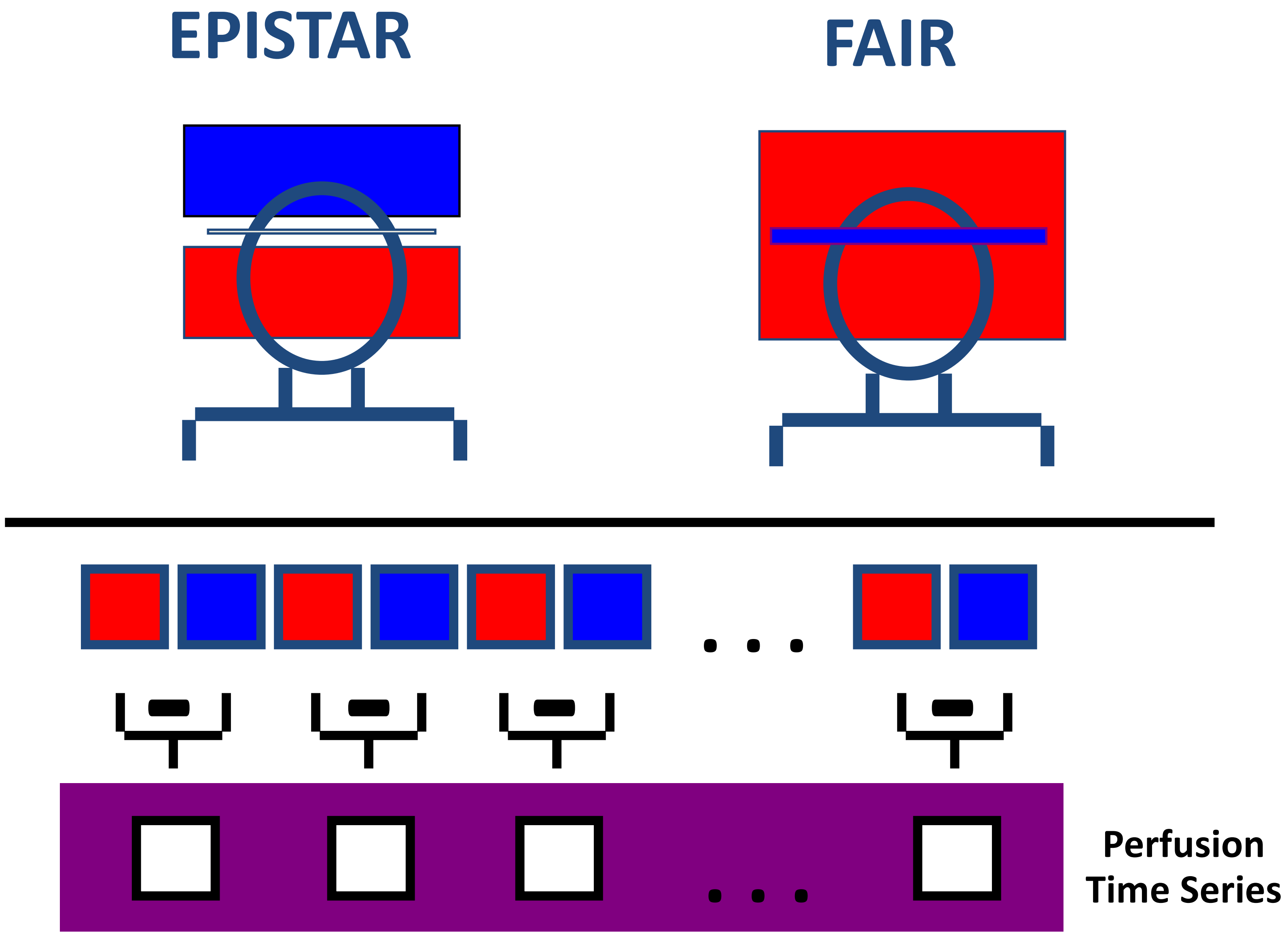
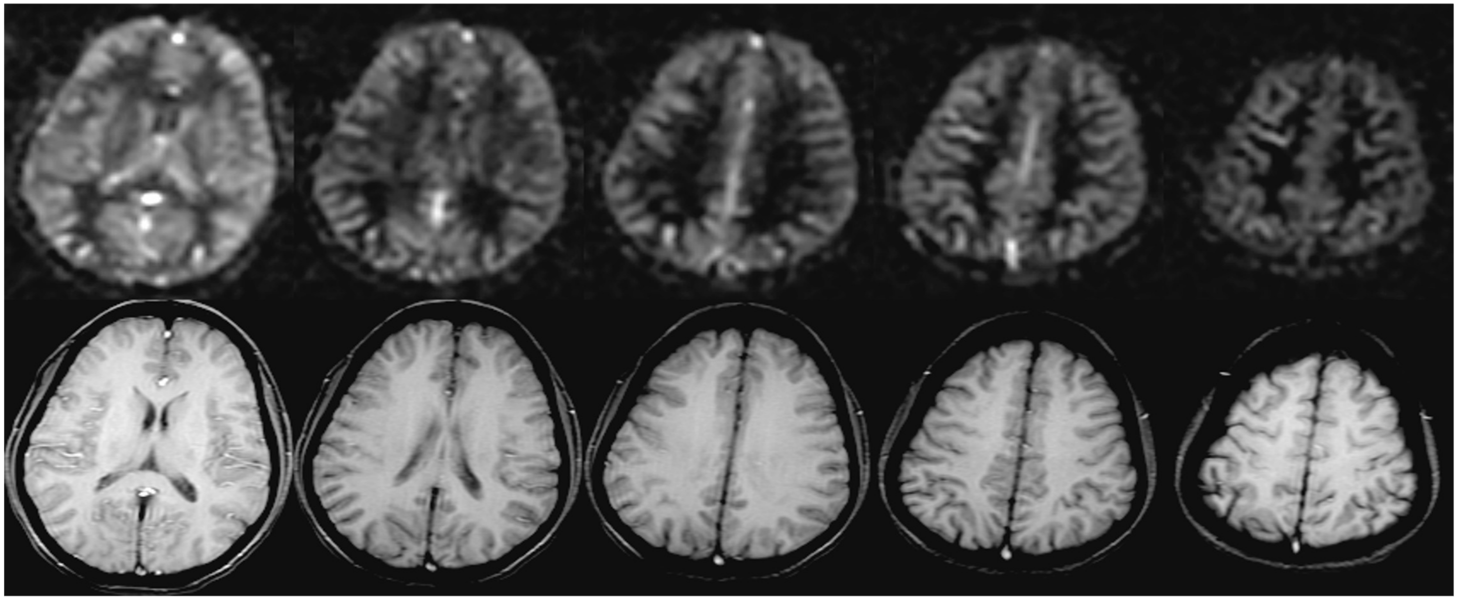
Arterial Spin Labeling

ASL



Arterial Spin Labeling



Williams, D. S., Detre, J. A., Leigh, J. S. & Koretsky, A. S. (1992) “Magnetic resonance imaging of perfusion using spin-inversion of arterial water.” **Proc. Natl. Acad. Sci. USA 89, 212-216.**

Edelman, R., Siewert, B. & Darby, D. (1994) “Qualitative mapping of cerebral blood flow and functional localization with echo planar MR imaging ans signal targeting with alternating radiofrequency (EPISTAR).” **Radiology 192, 1-8.**

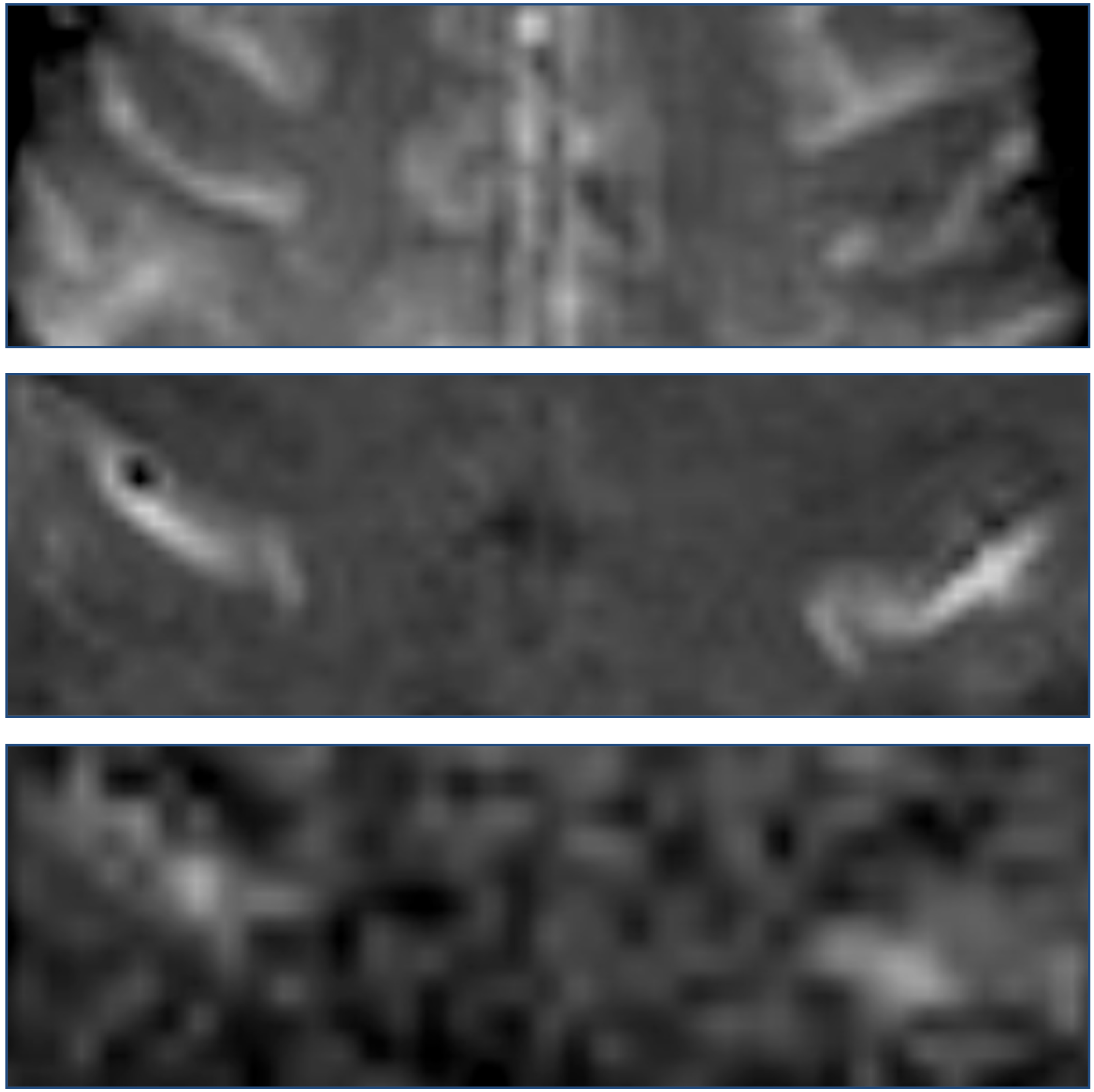
Kim, S.-G. (1995) “Quantification of relative cerebral blood flow change by flow-sensitive alternating inversion recovery (FAIR) technique: application to functional mapping.” **Magn. Reson. Med. 34, 293-301**.

Kwong, K. K. et al. (1995) “MR perfusion studies with T1-weighted echo planar imaging.”**Magn. Reson. Med. 34,878-887.**

Anatomy

BOLD

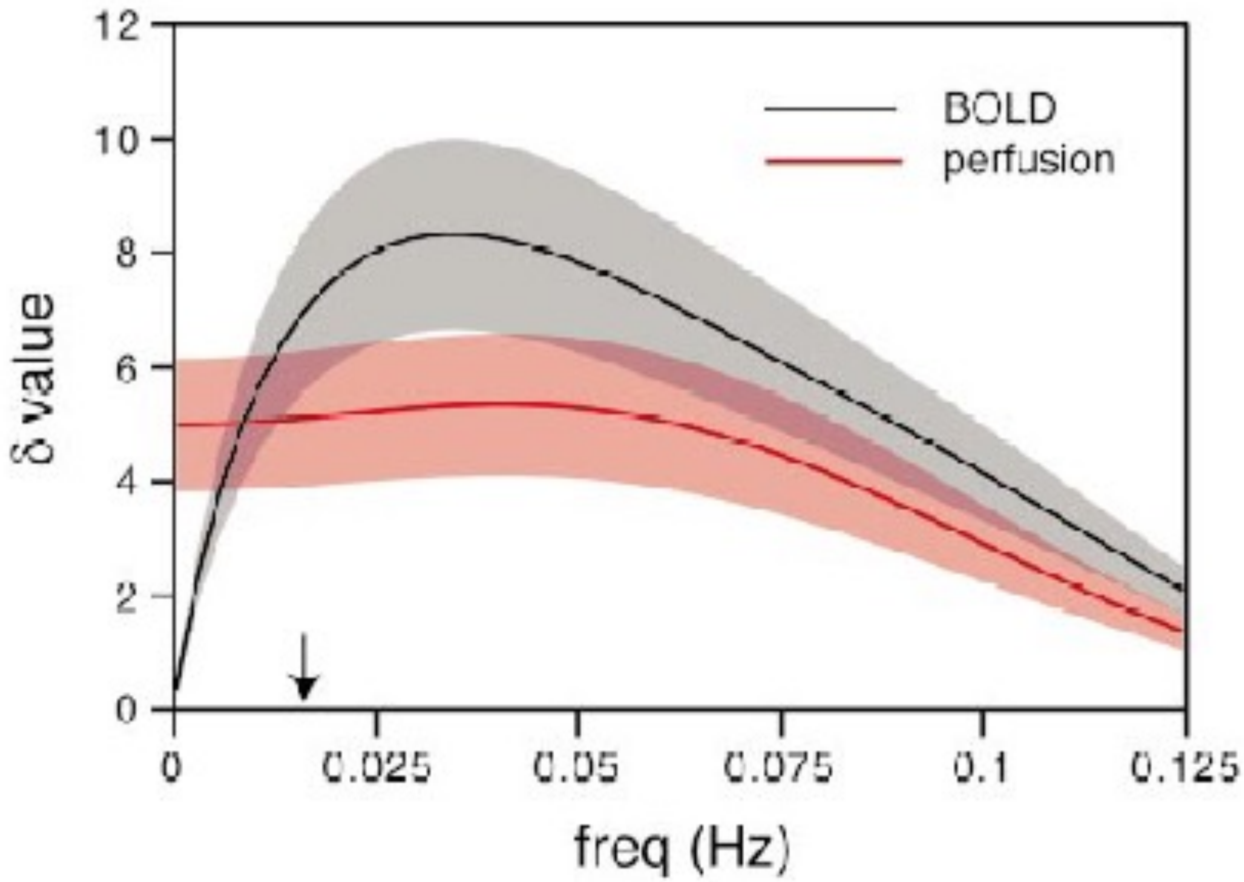
Perfusion



P. A. Bandettini, E. C. Wong, Magnetic resonance imaging of human brain function: principles, practicalities, and possibilities, *in* "Neurosurgery Clinics of North America: Functional Imaging" (M. Haglund, Ed.), p.345-371, W. B. Saunders Co., 1997.

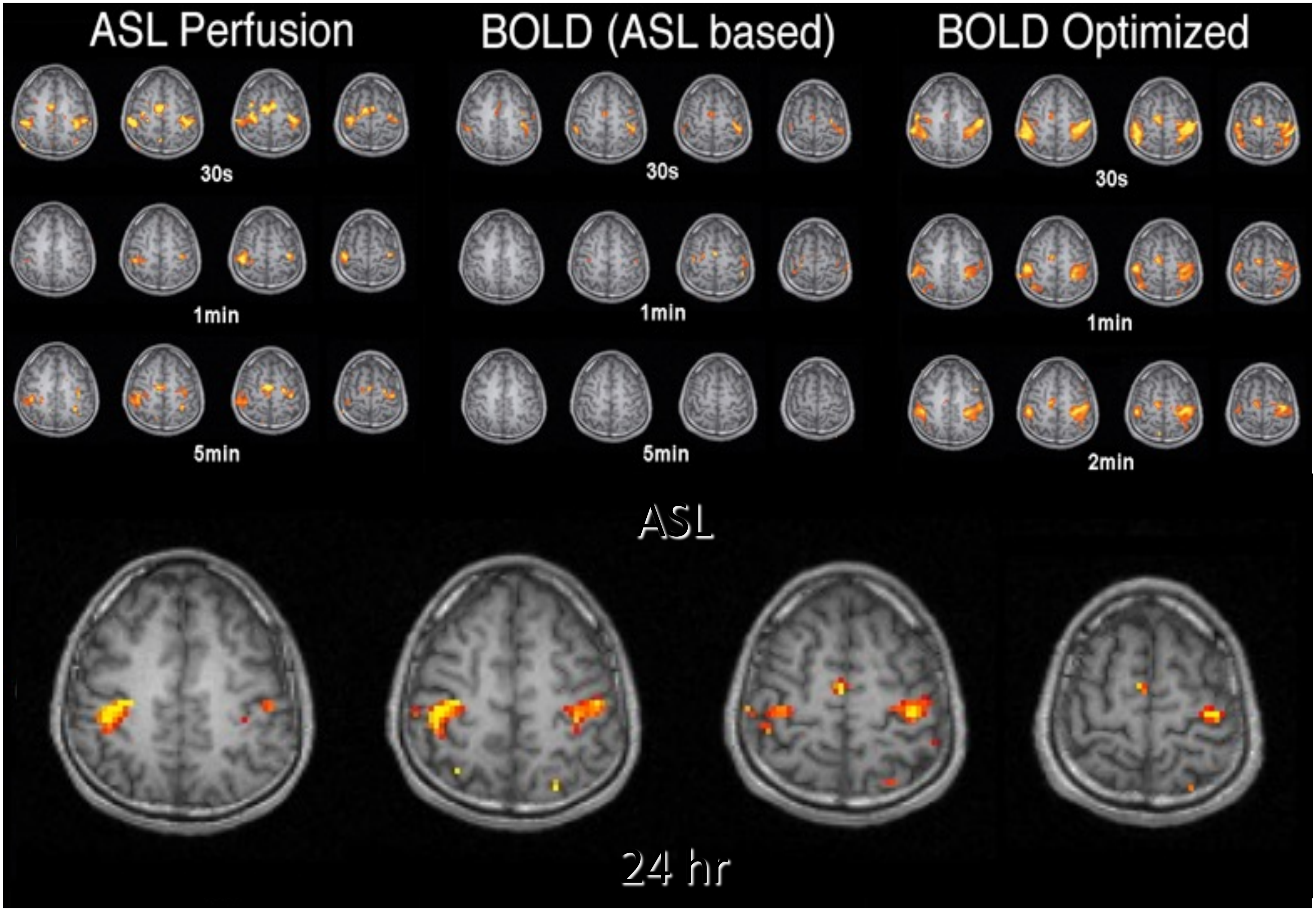
Arterial Spin Labeling

Better than BOLD for long duration activation…



GK Aguirre et al, (2002) NeuroImage 15 (3): 488-500

Perfusion vs. BOLD: Low Task Frequency



Arterial Spin Labeling

Pros:

Potentially quantitative
Localized to capillary effects
Stable over time
Allows baseline comparisons

Cons:

Slow (Prep times are up to 2 sec)
Limited spatial coverage of the slab
Low temporal SNR

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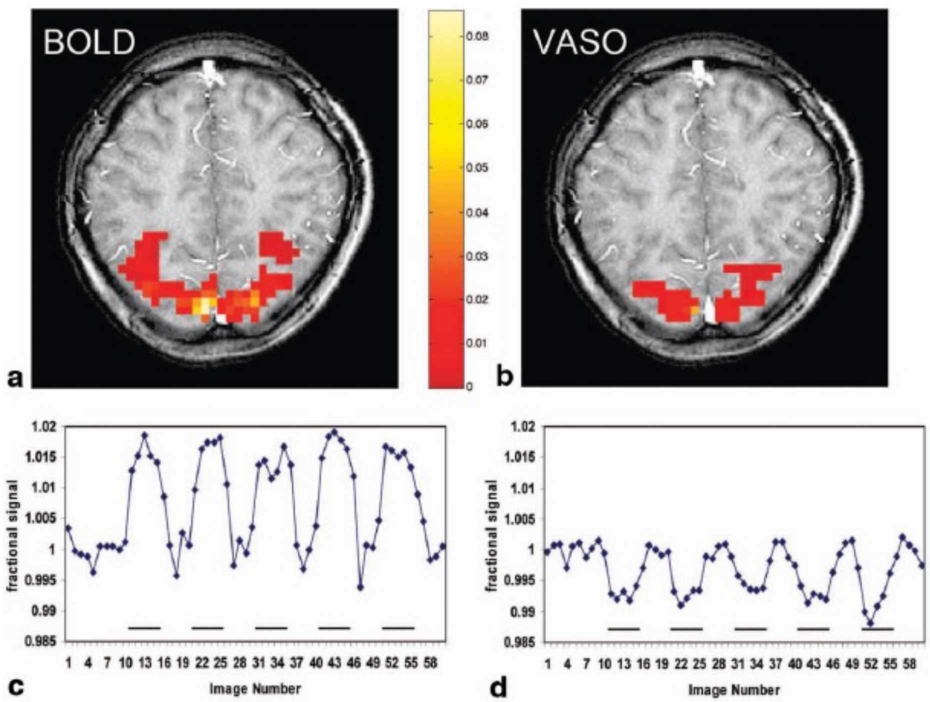
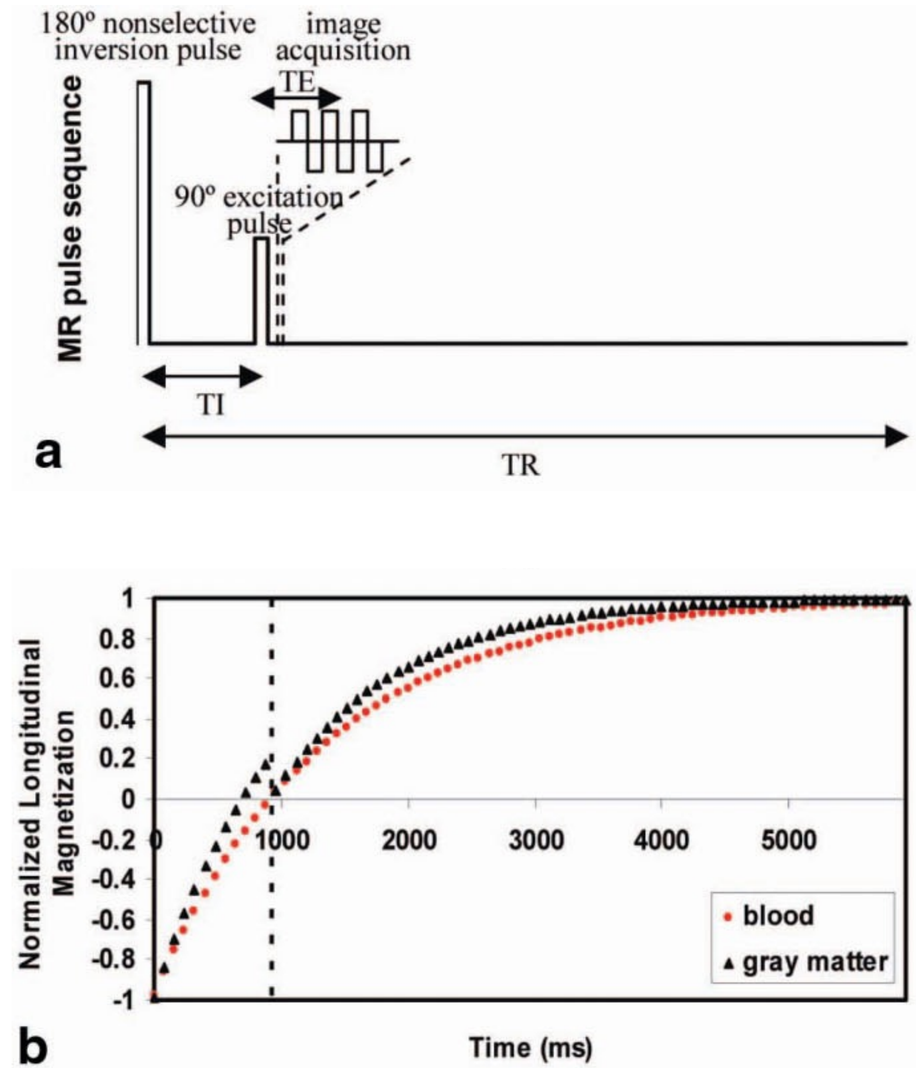
VASO





H. Lu et al. Magnetic Resonance in Medicine 50 (2), pp. 263-274

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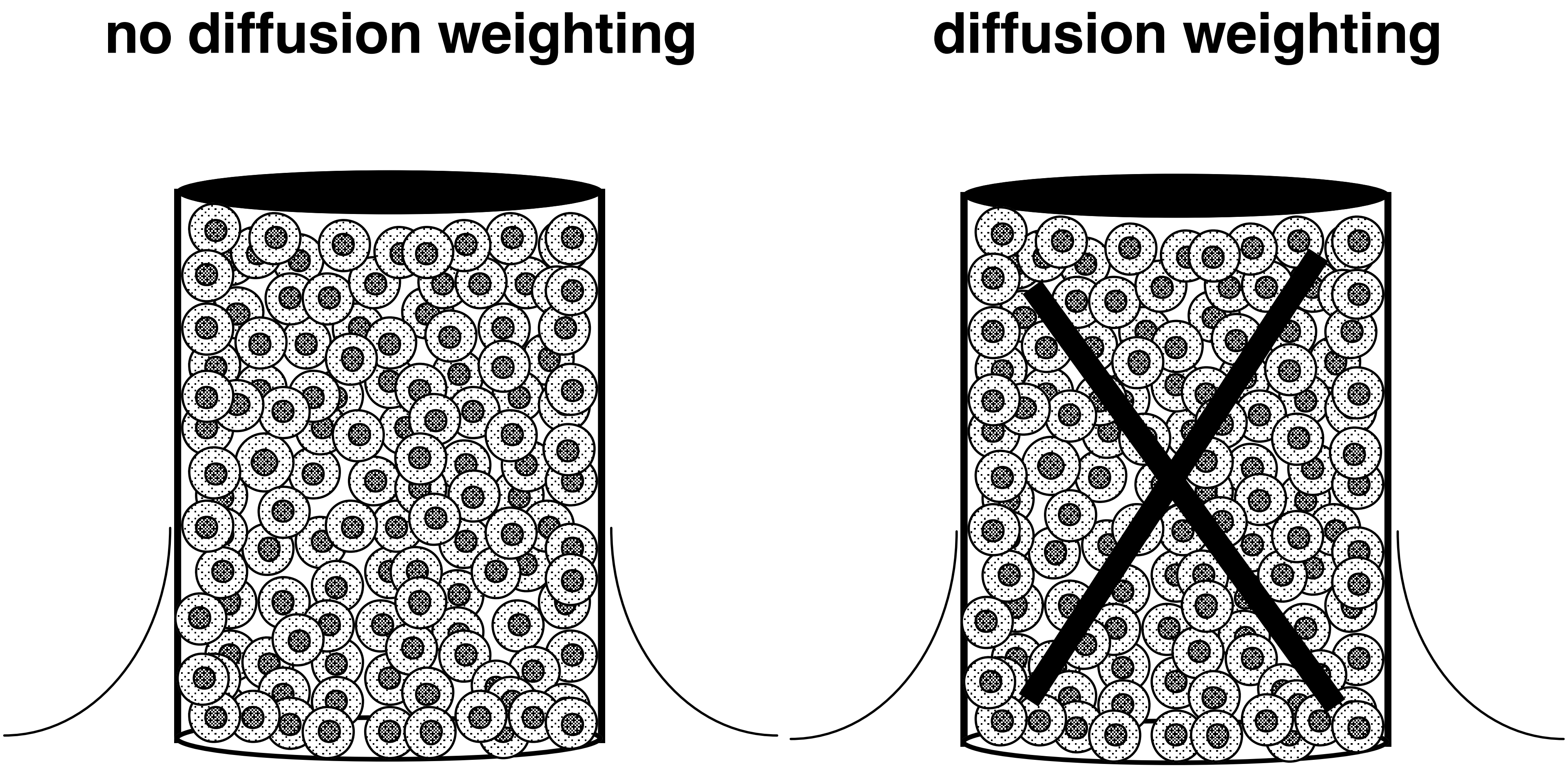
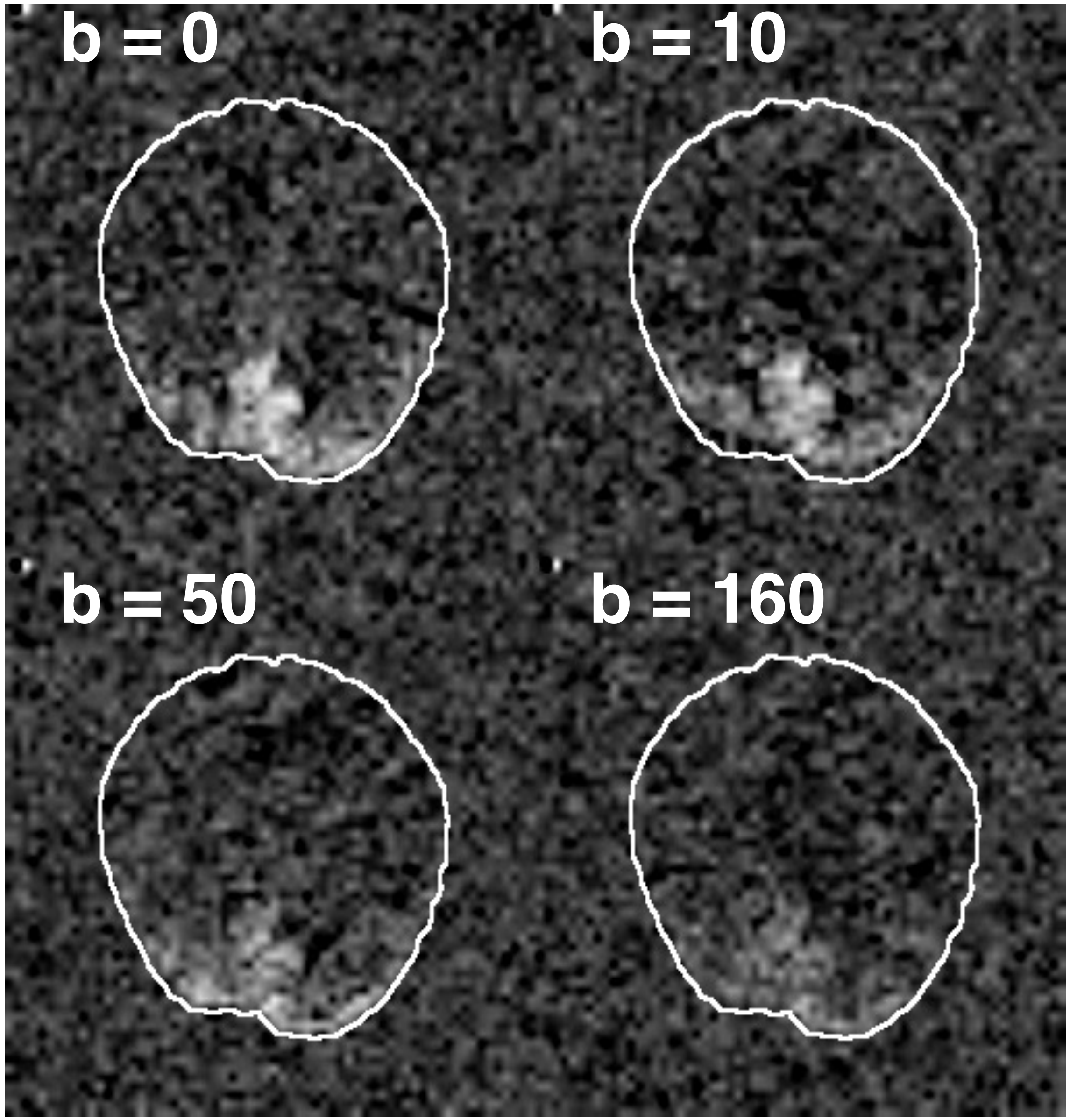
Low b Diffusion Weighting

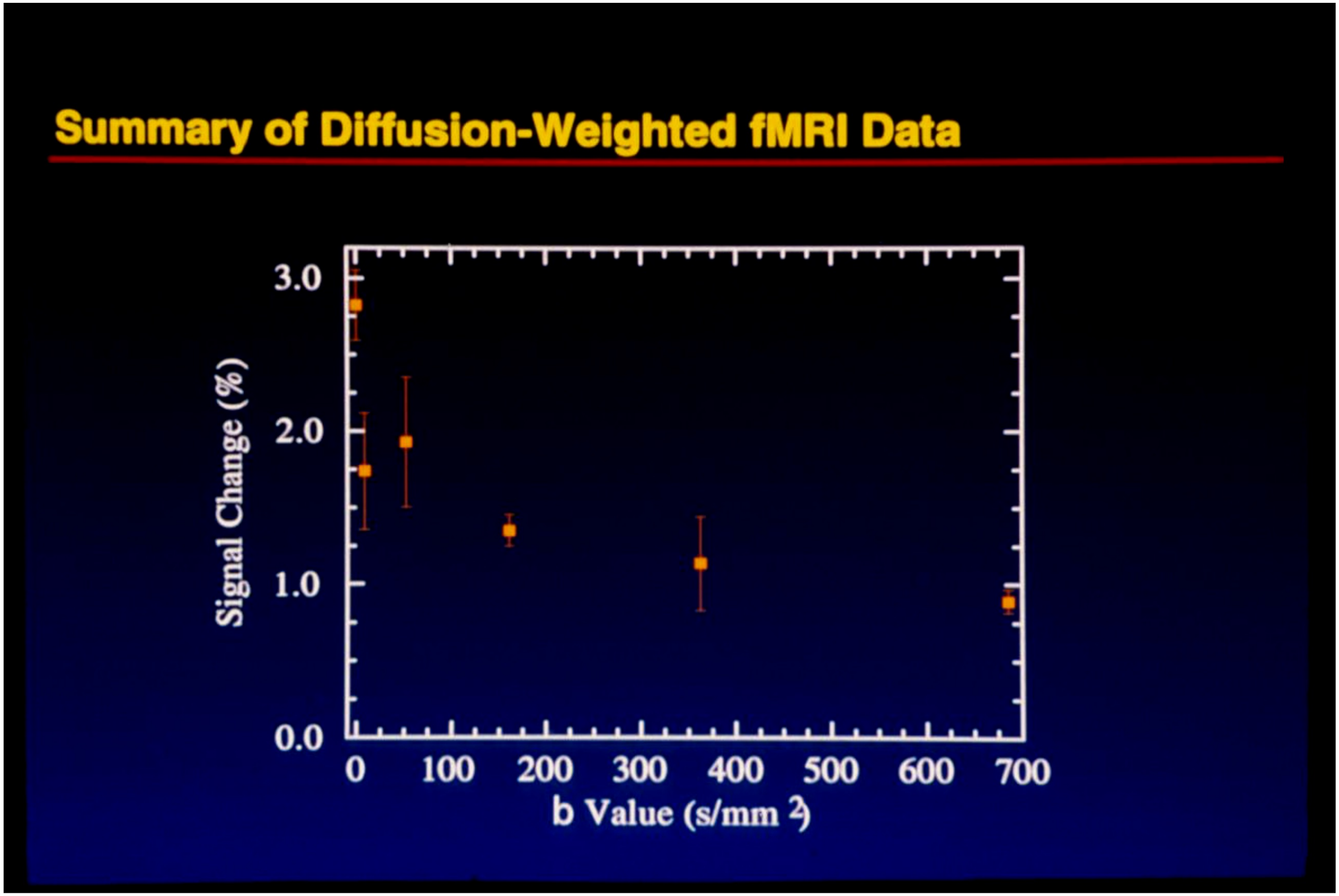


J. L. Boxerman, et al. MRM, 34, 4-10, (1995)
A. W. Song, et al. MRM, 35, 155-158 (1996)

Low b Diffusion Weighting



Low b Diffusion Weighting



Pros:

- Remove intravascular signal (i.e. most of large vessel signal)

Cons:

- Gradient-echo still sensitive to extravascular large vessels.
- Diffuion weighting and Spin-echo leaves one with no functional signal.

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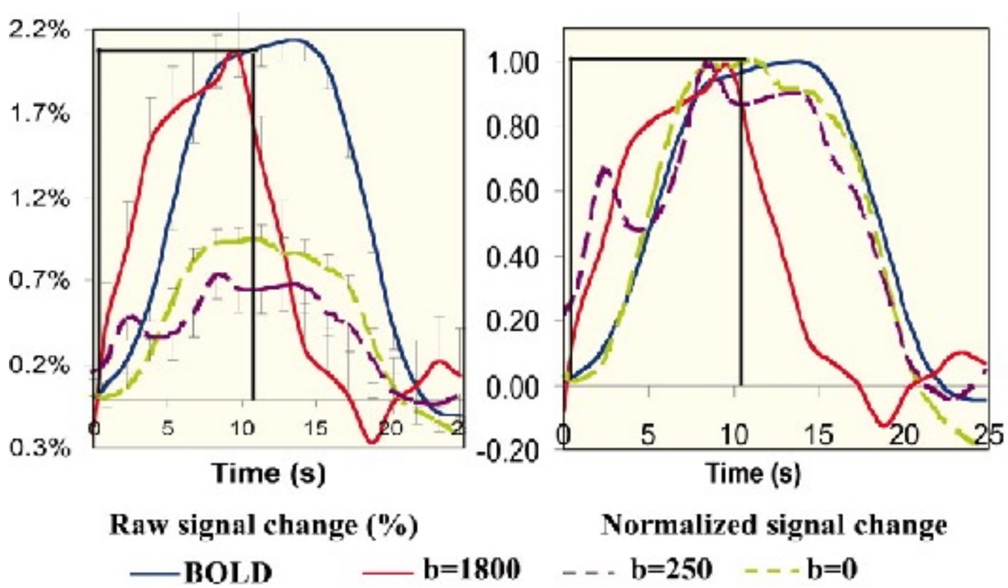
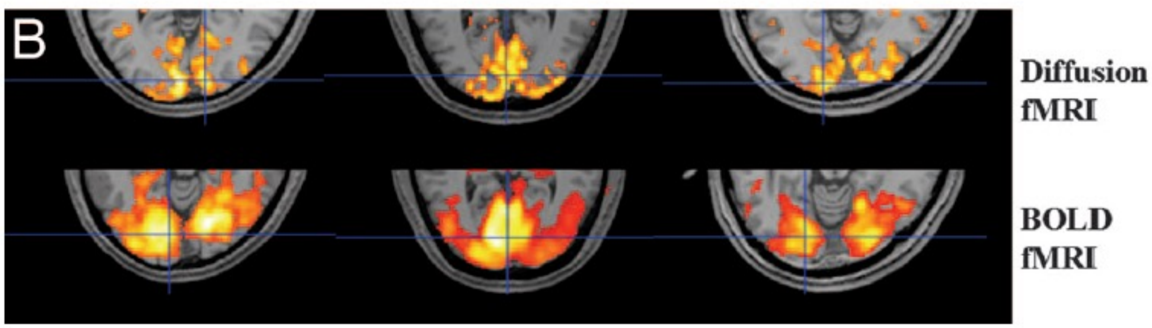
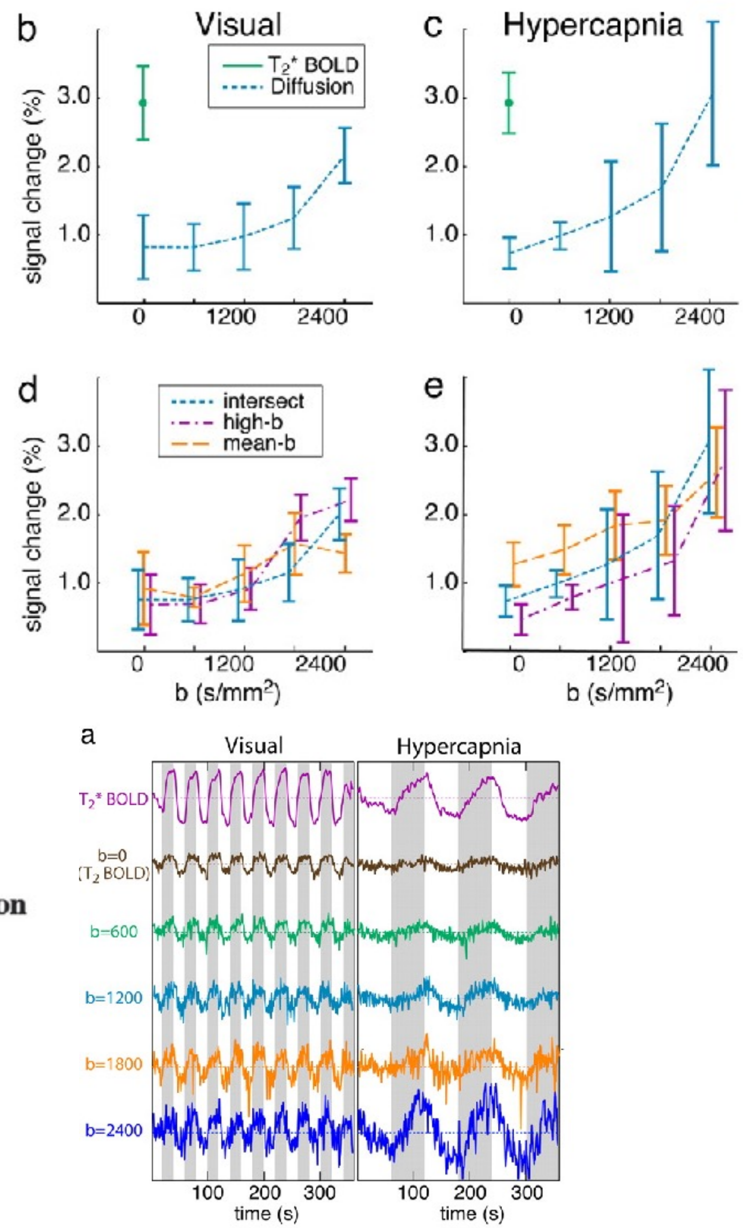
High b Diffusion Weighting







D. Le Bihan, et al Proceedings of the National Academy of Sciences of the United States of America 103 (21), pp. 8263-8268

K. Miller, et al Proceedings of the National Academy of Sciences of the United States of America 104 (52), pp. 20967-20972

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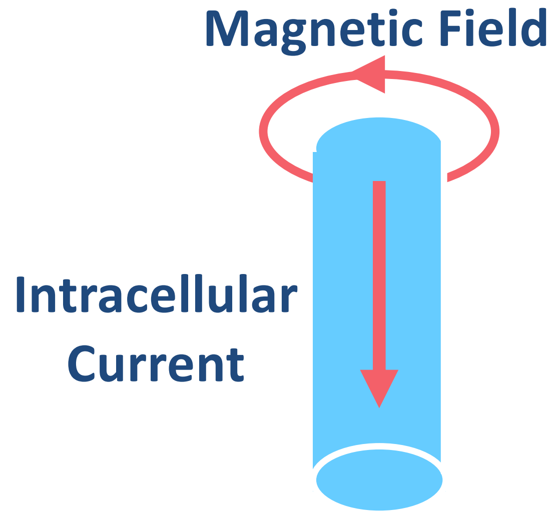
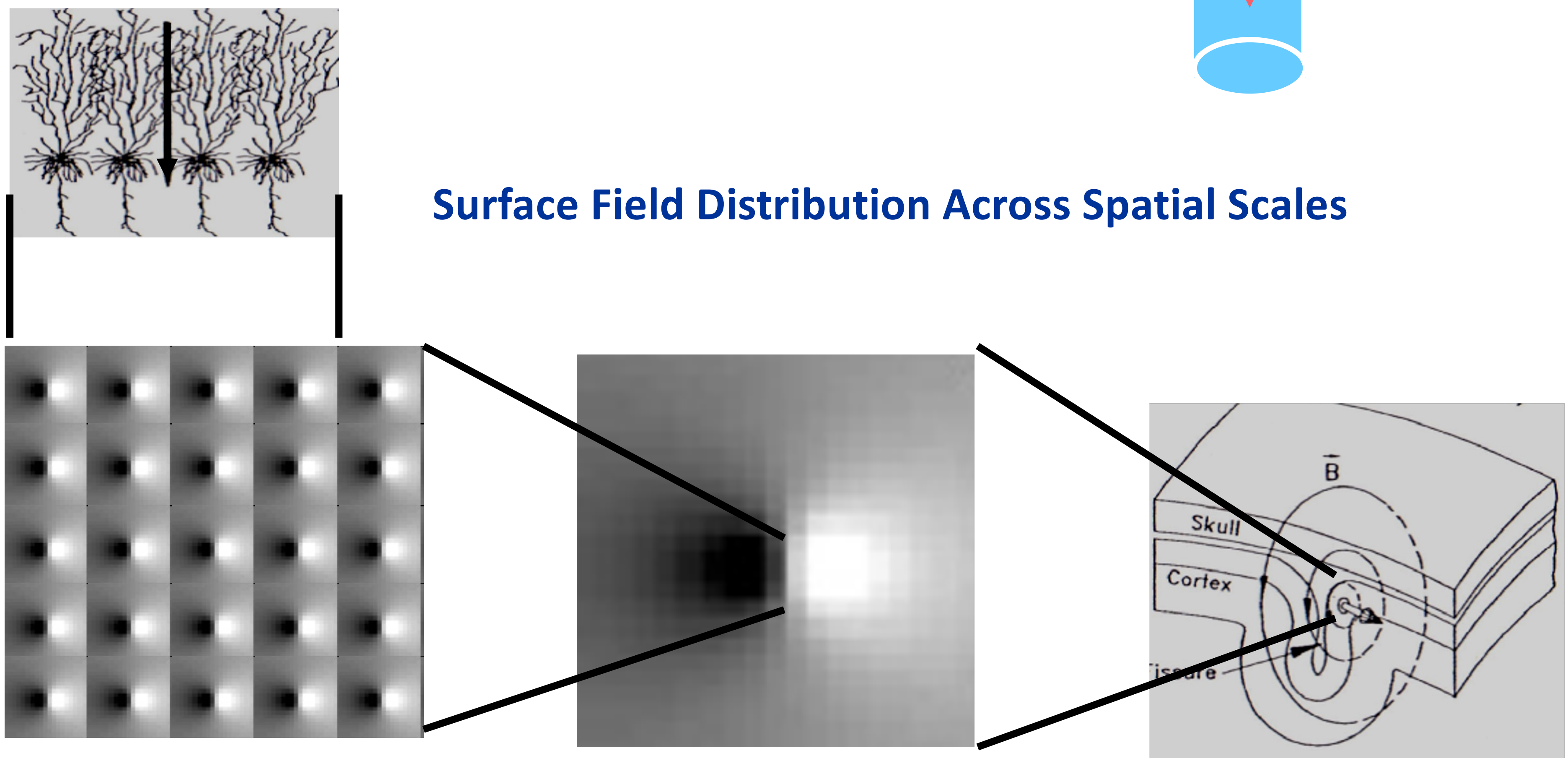
Neuronal Current Imaging



Surface Field Distribution Across Spatial Scales

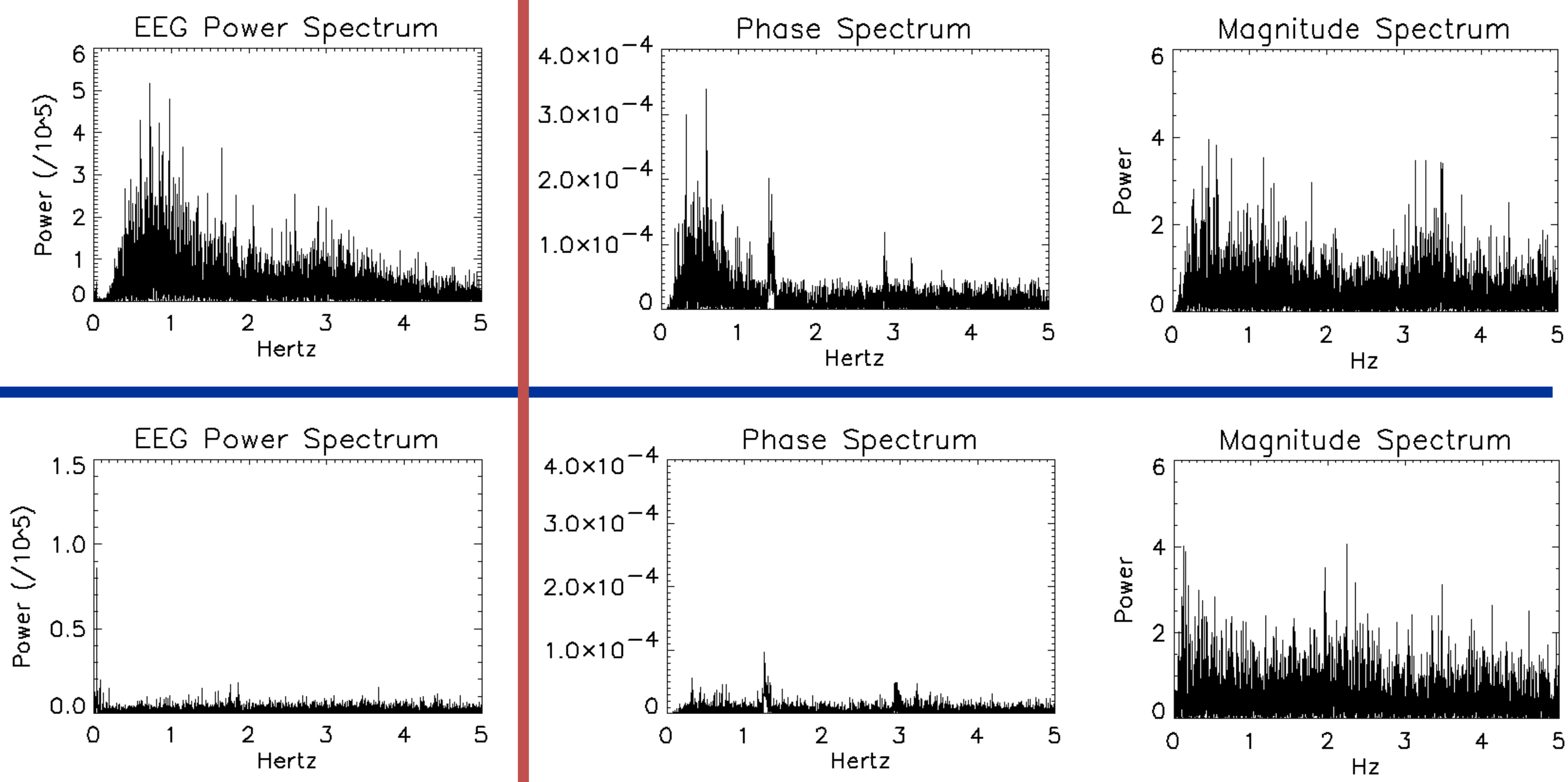


Adapted from: J.P. Wikswo Jr et al. *J Clin Neurophy* 8(2): 170-188, 1991

EEG

MR (7T)

TTX



Power decrease between PRE & TTX EEG : ~ 81%

Decrease between PRE & TTX MR phase: ~ 70%

Decrease between PRE & TTX MR magnitude: ~ 8%

N. Petridou, D. Plenz, A. C. Silva, J. Bodurka, M. Loew, P. A. Bandettini, *Proc. Nat'l. Acad. Sci. USA*. 103, 16015-16020 (2006).

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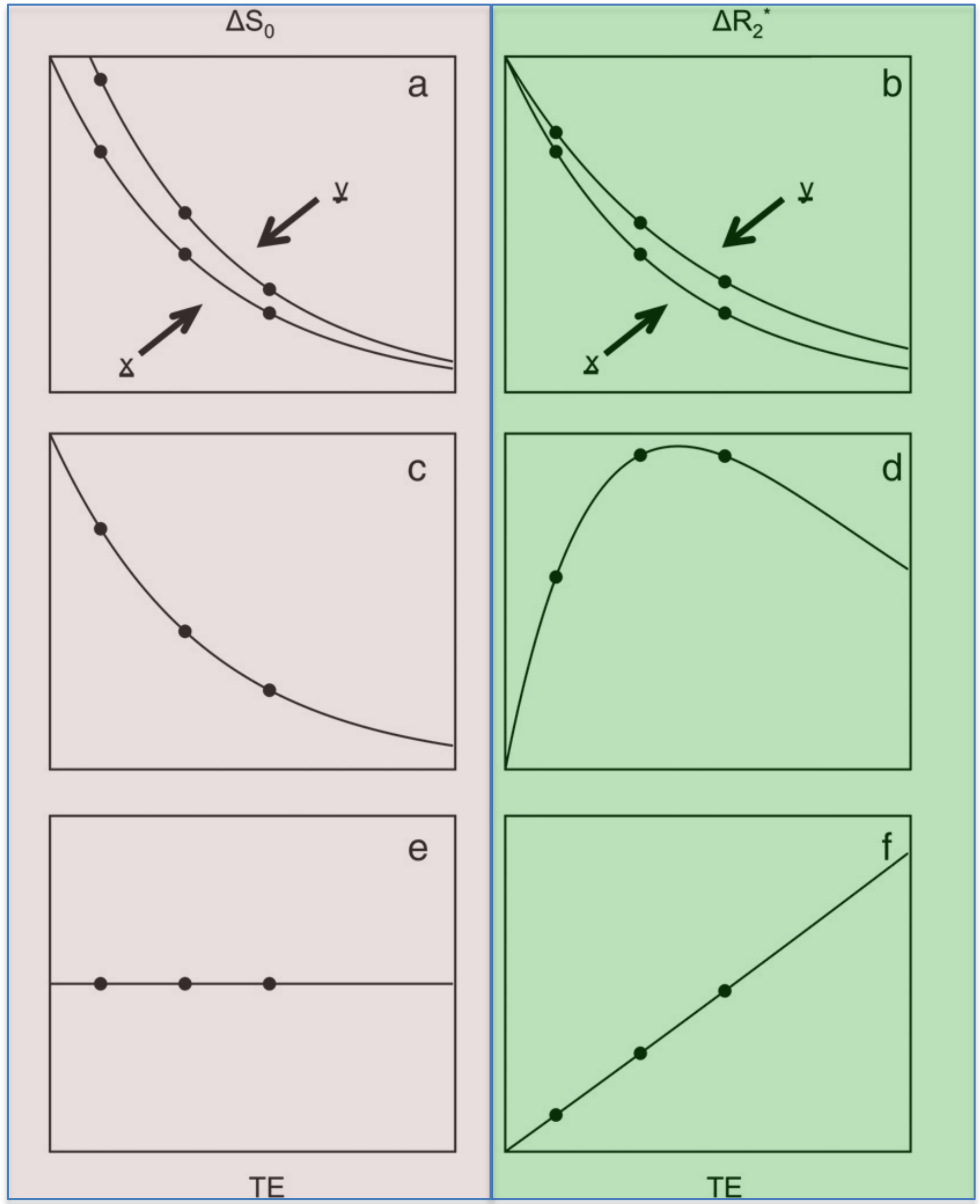
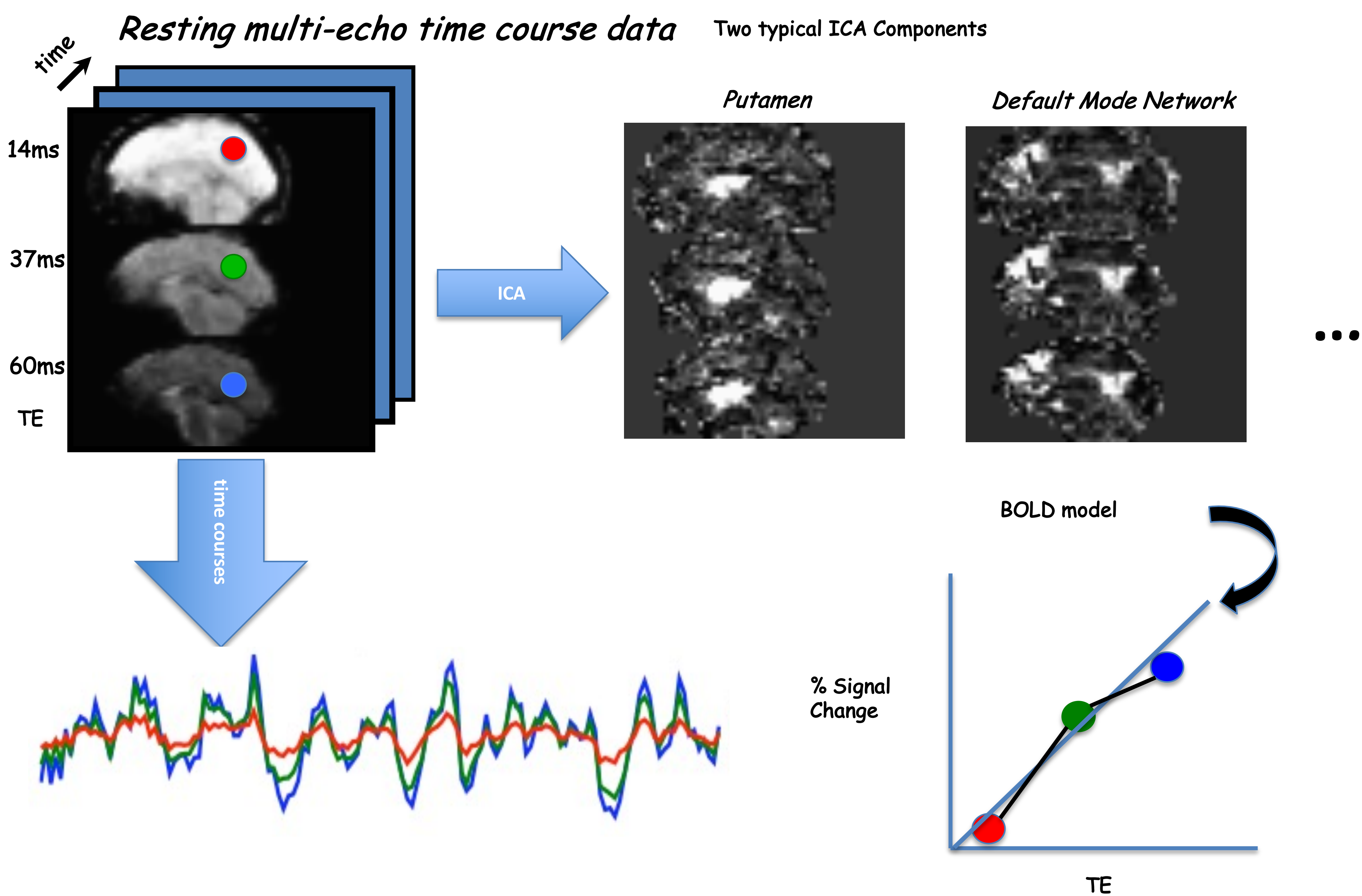
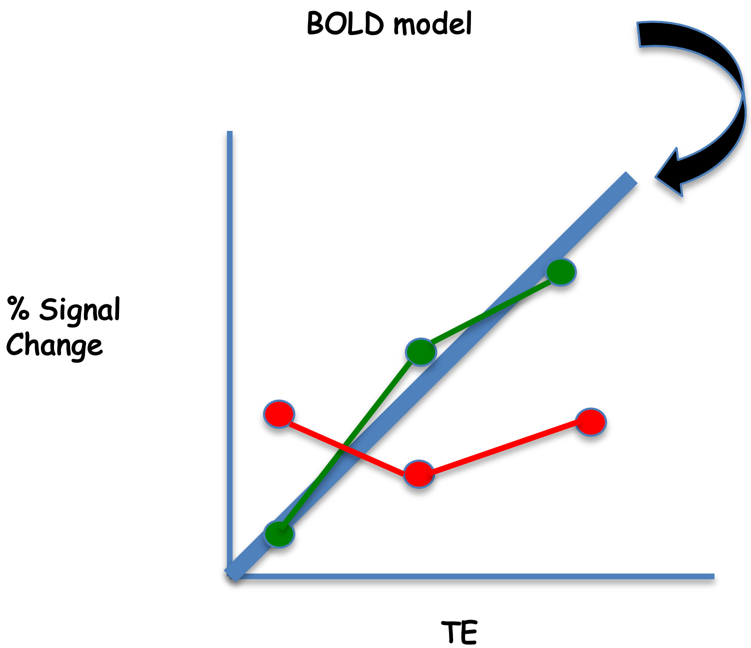
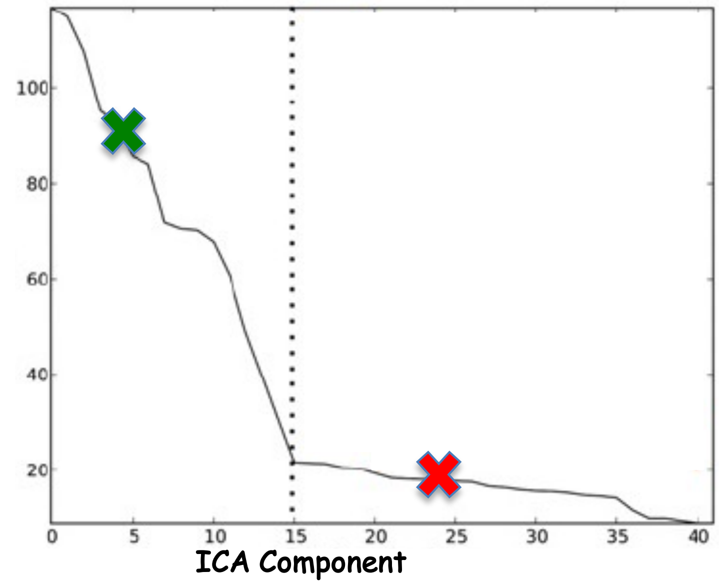
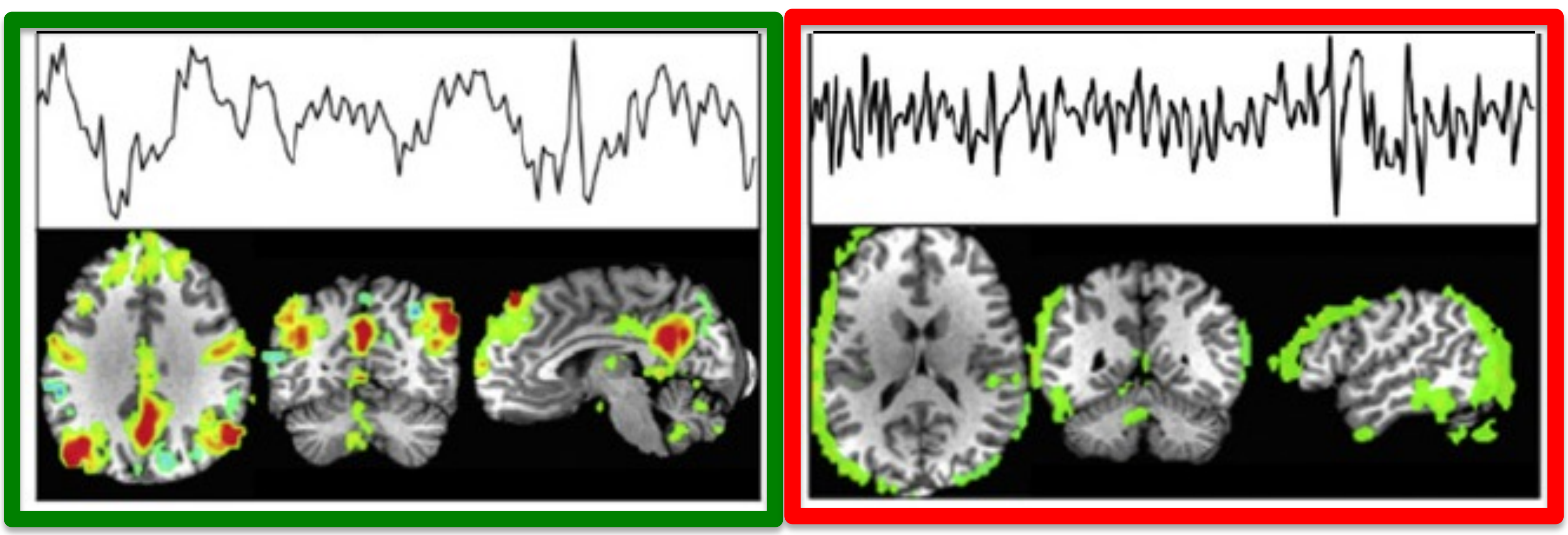

Non-BOLD
BOLD
Rest and activation
Difference
Percent change
ΔS_0
ΔR_2^*
a
b
c
d
e
f
x
y
TE
TE


Resting multi-echo time course data
Two typical ICA Components
time
14ms
37ms
60ms
TE
ICA
Putamen
Default Mode Network
...
time courses
BOLD model
% Signal
Change
TE

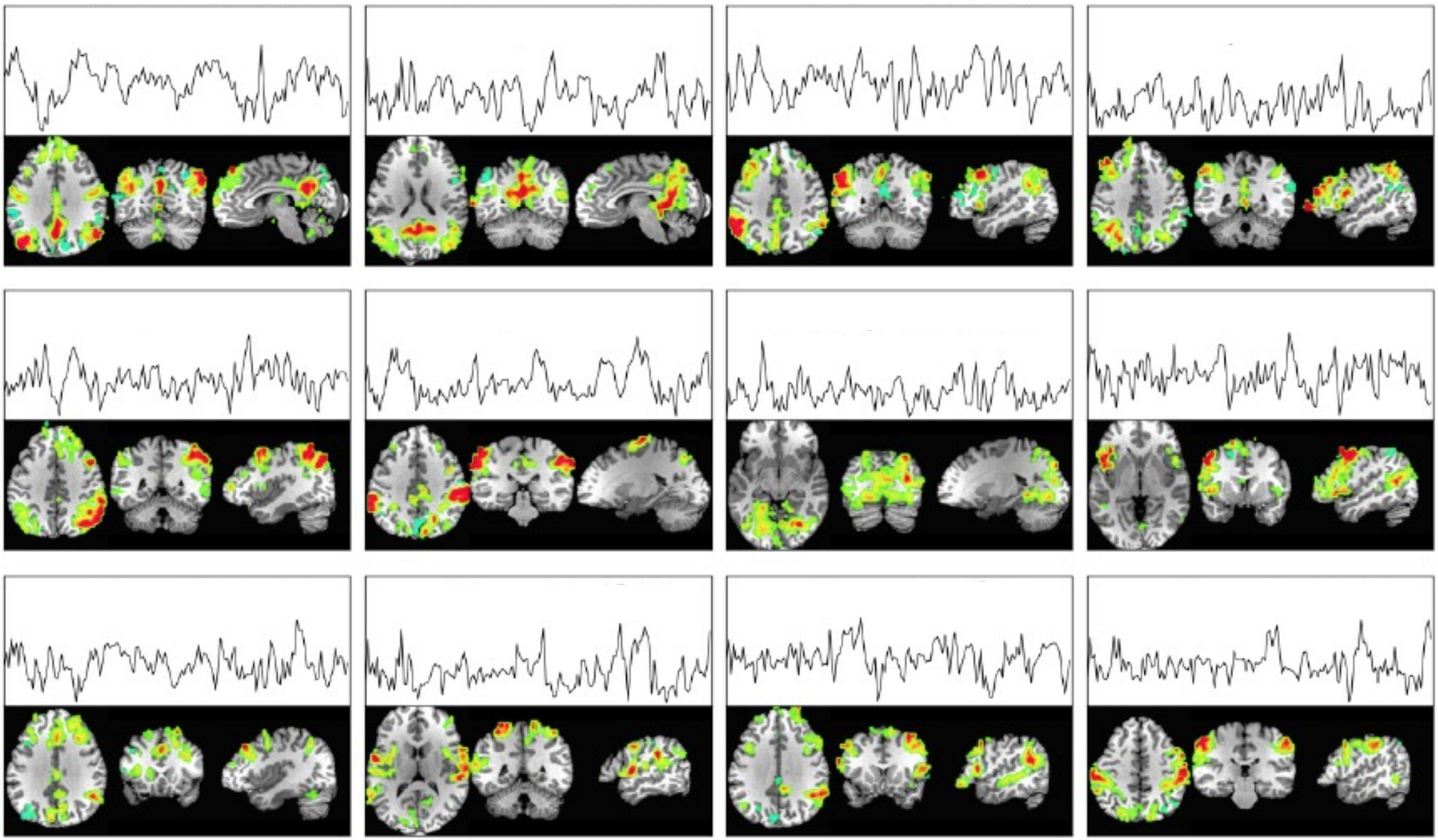


Goodness of fit
to BOLD
model

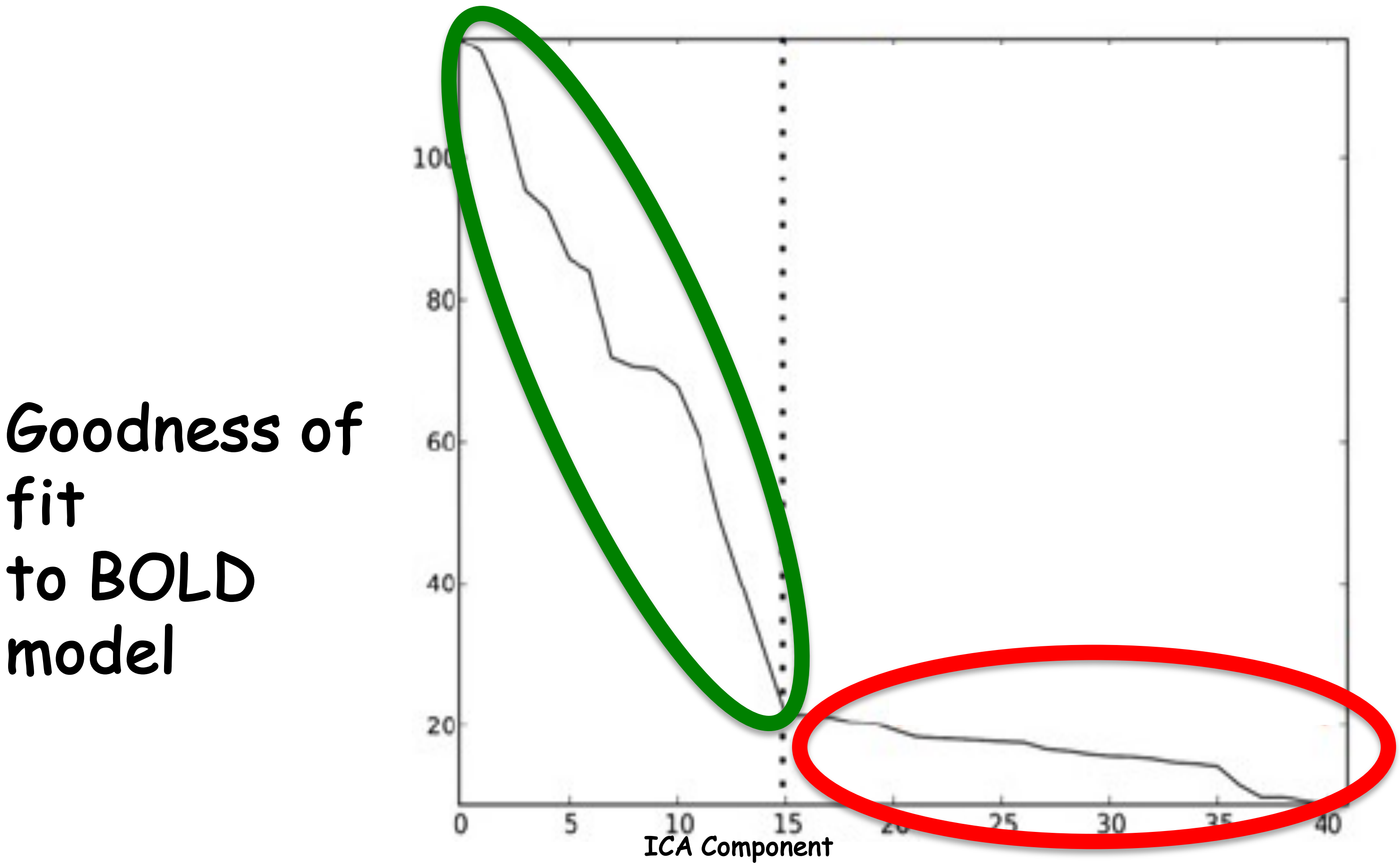




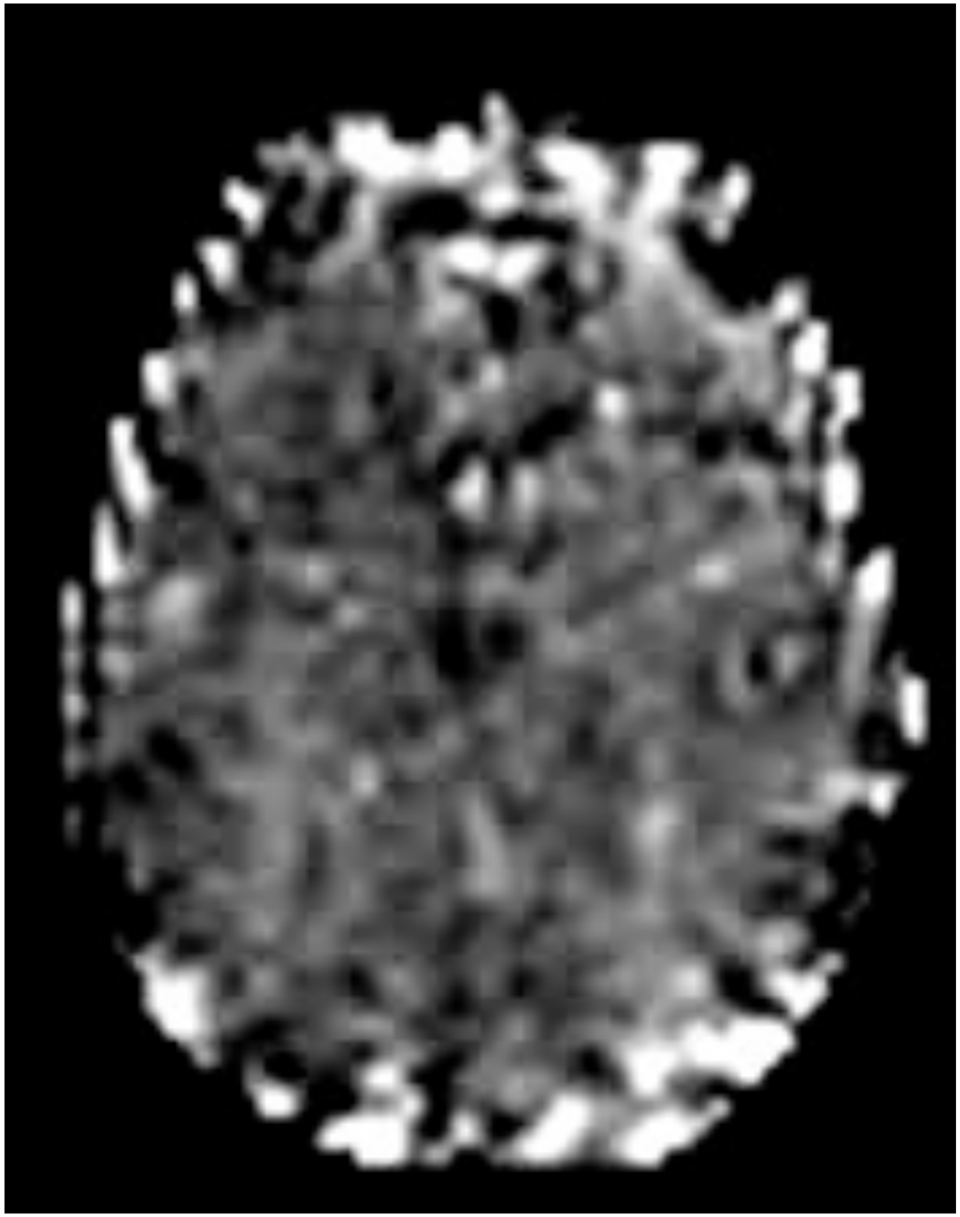
Automatic Selection of BOLD Component Maps



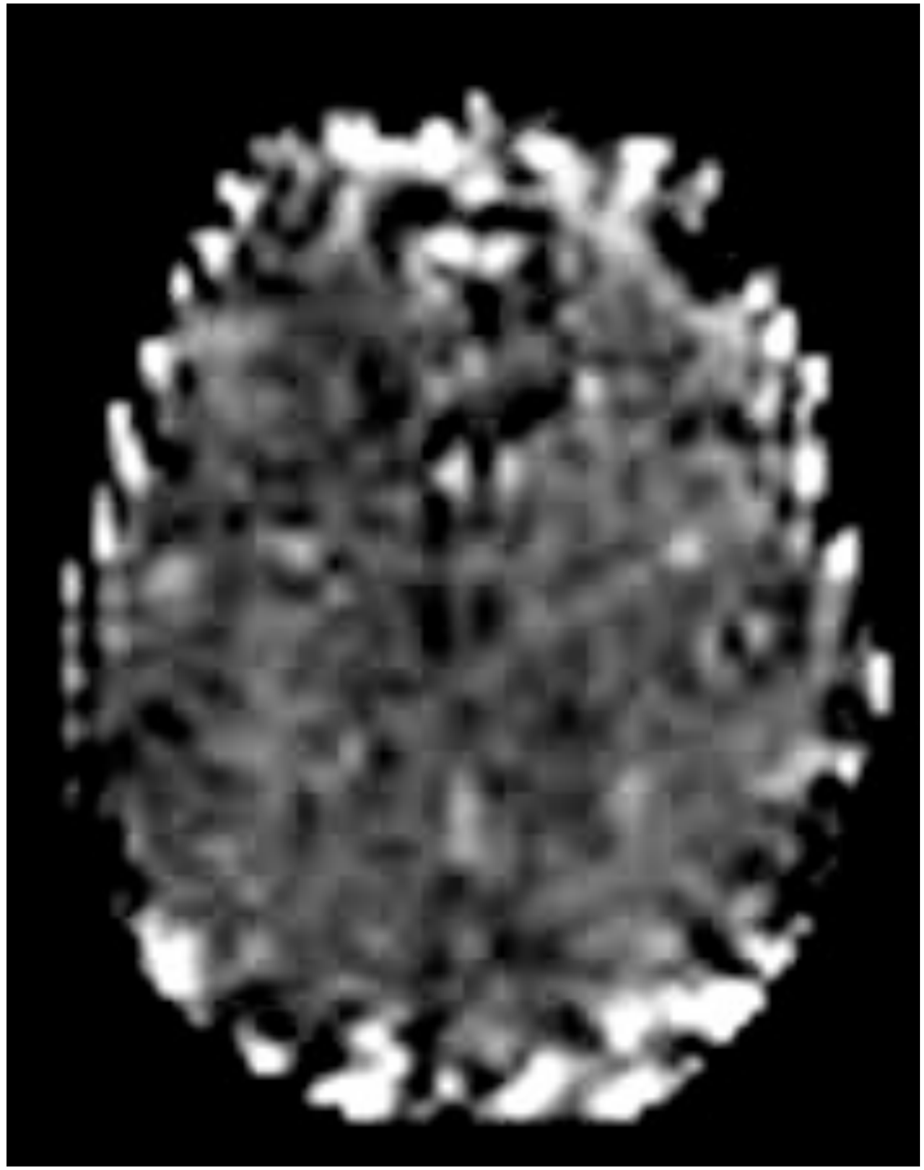
Clustering is extremely robust on small groups and on individuals when using multi-echo selected BOLD Components.



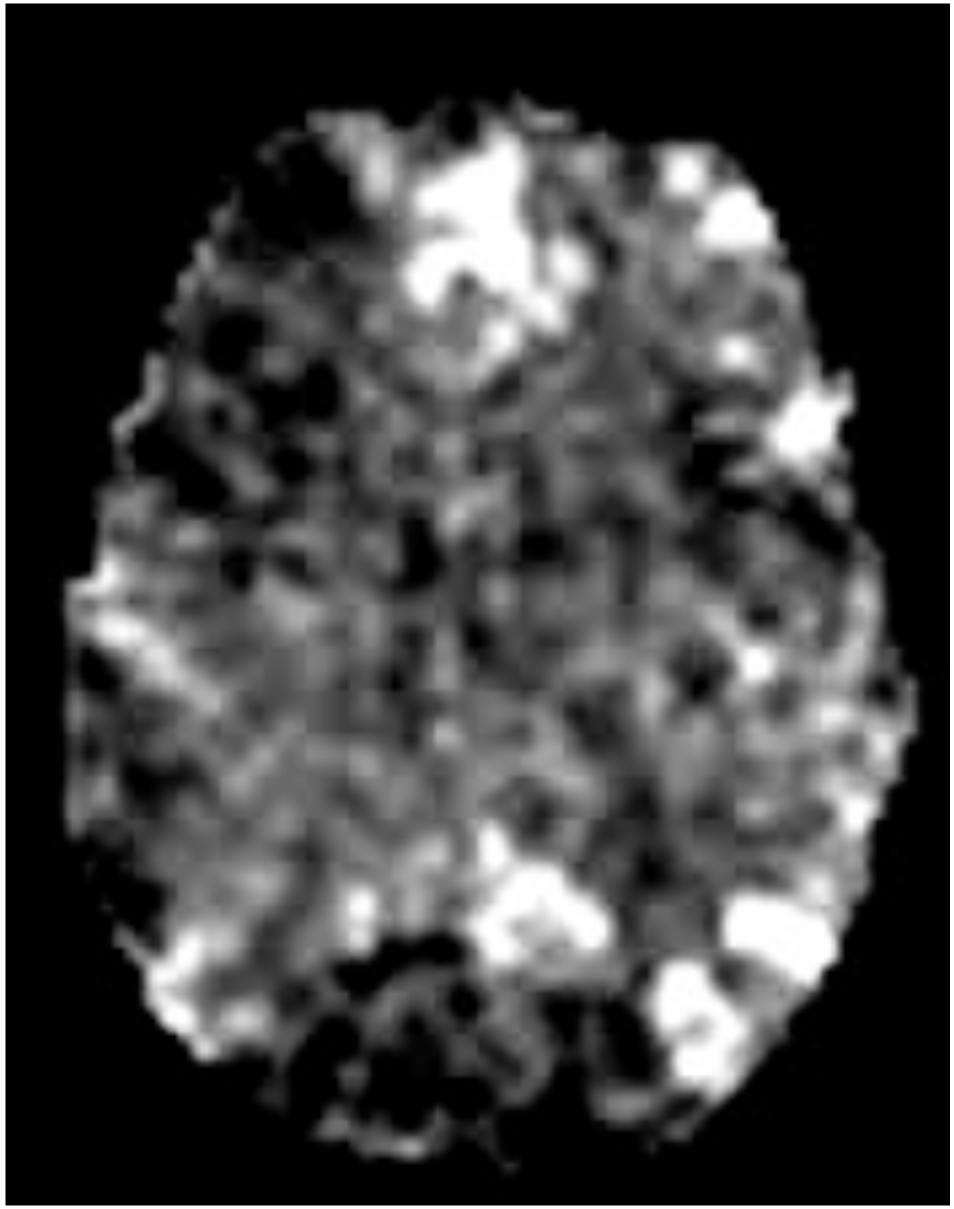
Typical raw time series signal



Non-BOLD fluctuations…what is regressed out.



After non-BOLD noise is regressed out…this is what remains



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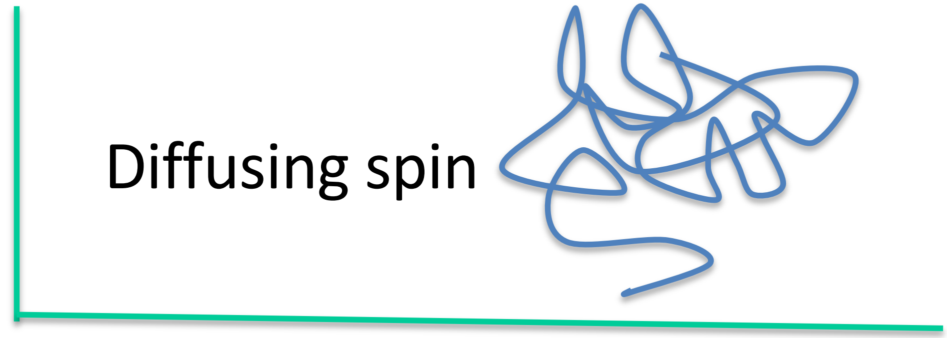

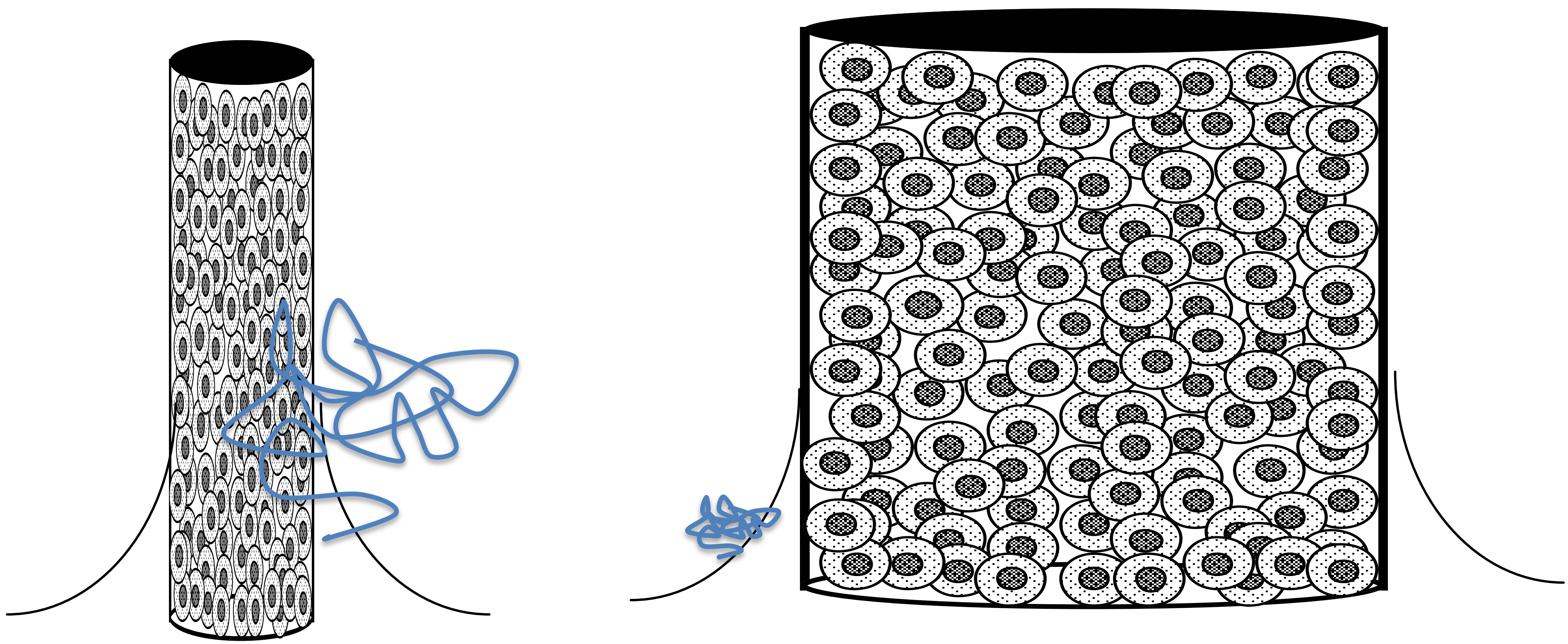

δ**phase = 0**
δ**magnitude = 1**

δ**phase = 1**
δ**magnitude = 1**

NeuroImage 49 (2010) 3149–3160

Contents lists available at ScienceDirect

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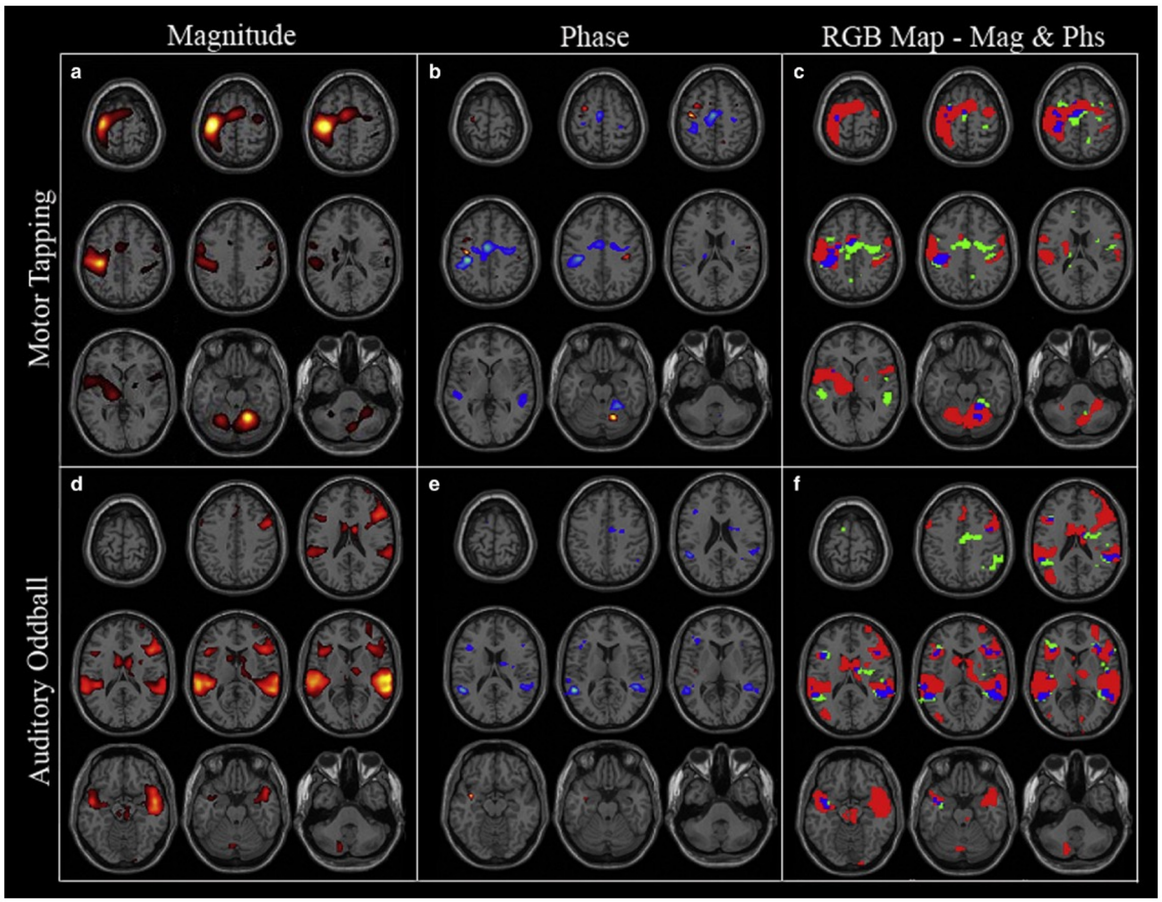
journal homepage: www.elsevier.com/locate/ynimg

Technical Note

Changes in fMRI magnitude data and phase data observed in block-design and event-related tasks

Sunil Kumar Arja [a,b,*], Zhaomei Feng [a,b], Zikuan Chen [a], Arvind Caprihan [a], Kent A. Kiehl [a], Tülay Adali [c], Vince D. Calhoun [a,b]

[a] The Mind Research Network, 1101 Yale Blvd NE, Albuquerque, NM 87131, USA
[b] Department of ECE, University of New Mexico, Albuquerque, NM, USA
[c] Department of CSEE, University of Maryland, Baltimore County, Baltimore, MD, USA



Red = mag
Green=mag+phase
Blue = phase

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Gating and variable TR correction

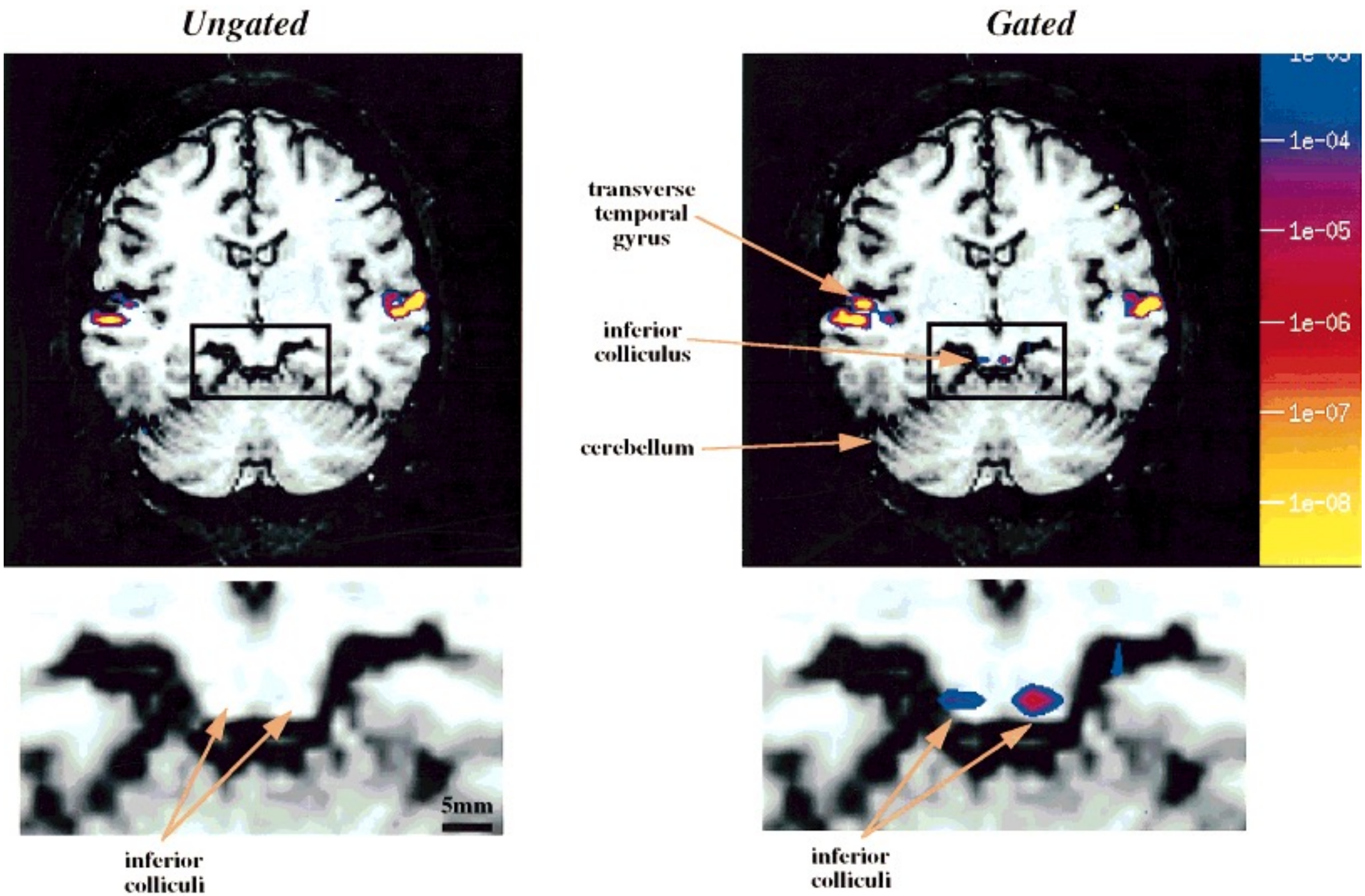
◆ Human Brain Mapping 6:33–41(1998) ◆

Imaging Subcortical Auditory Activity in Humans

A.R. Guimaraes,[1,2*] J.R. Melcher,[3] T.M. Talavage,[2,3] J.R. Baker,[1,2] P. Ledden,[1]
B.R. Rosen,[1,2] N.Y.S. Kiang,[2–4] B.C. Fullerton,[2,3] and R.M. Weisskoff[1,2]

[1]*MGH-NMR Center, Department of Radiology, Massachusetts General Hospital, Charlestown, Massachusetts 02129*
[2]*Harvard-Massachusetts Institute of Technology Division of Health, Sciences and Technology, Cambridge, Massachusetts 02139*
[3]*Eaton-Peabody Laboratory, Massachusetts Eye and Ear Infirmary, Boston, Massachusetts*
[4]*Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

Gating and variable TR correction



A. R. Guimaraes et al., Human Brain Mapping 6, 33-41 (1998)

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Event-related optimizing for response characterization rather than mapping

NeuroImage **15**, 252–264 (2002)
doi:10.1006/nimg.2001.0964, available online at http://www.idealibrary.com on IDEAL®

RAPID COMMUNICATION

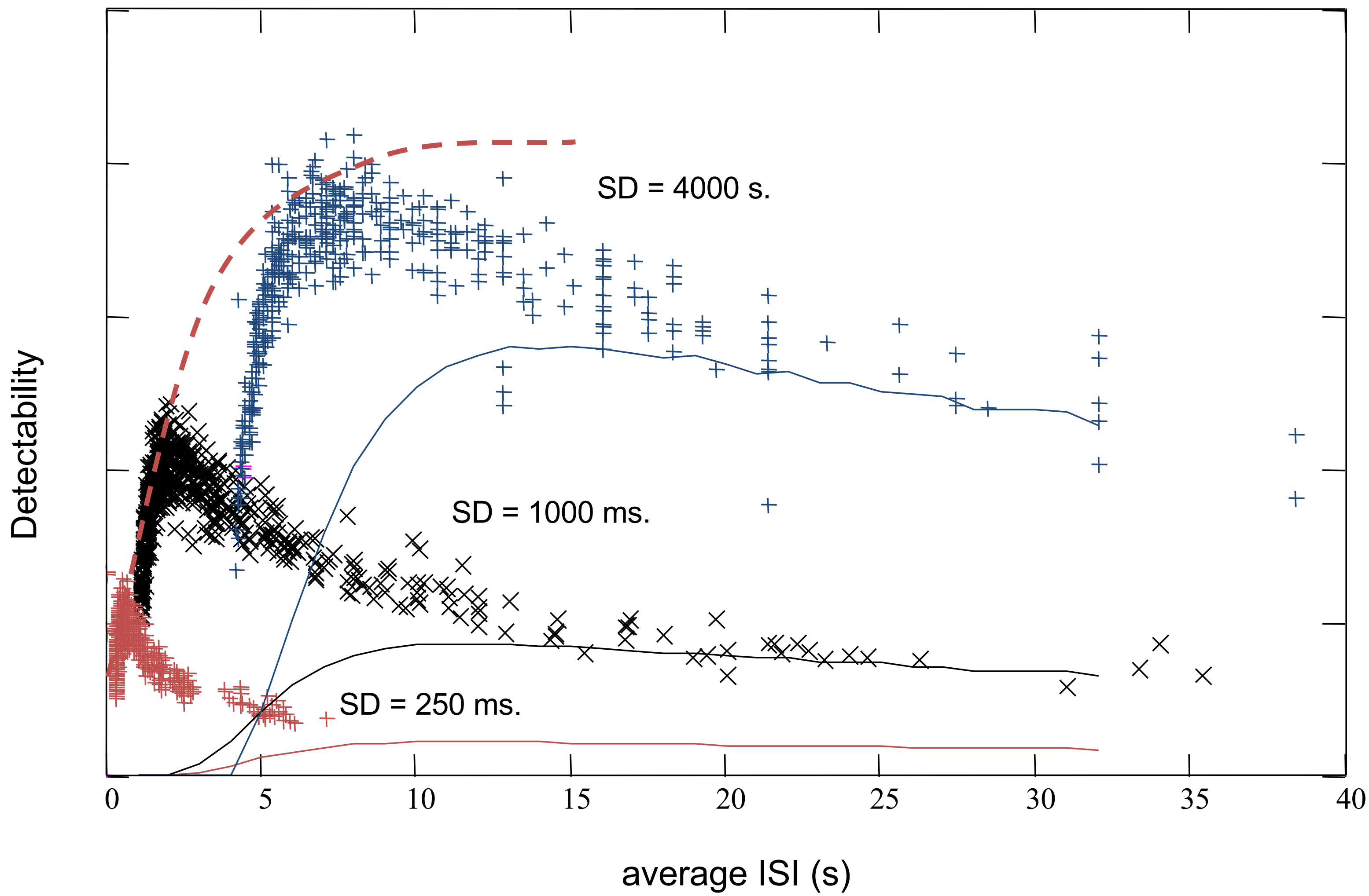
Detection versus Estimation in Event-Related fMRI: Choosing the Optimal Stimulus Timing

Rasmus M. Birn, Robert W. Cox,* and Peter A. Bandettini

*3T Functional Neuroimaging Core, National Institute of Mental Health, and *Scientific and Statistical Computing Core, National Institute of Mental Health, Bethesda, Maryland*

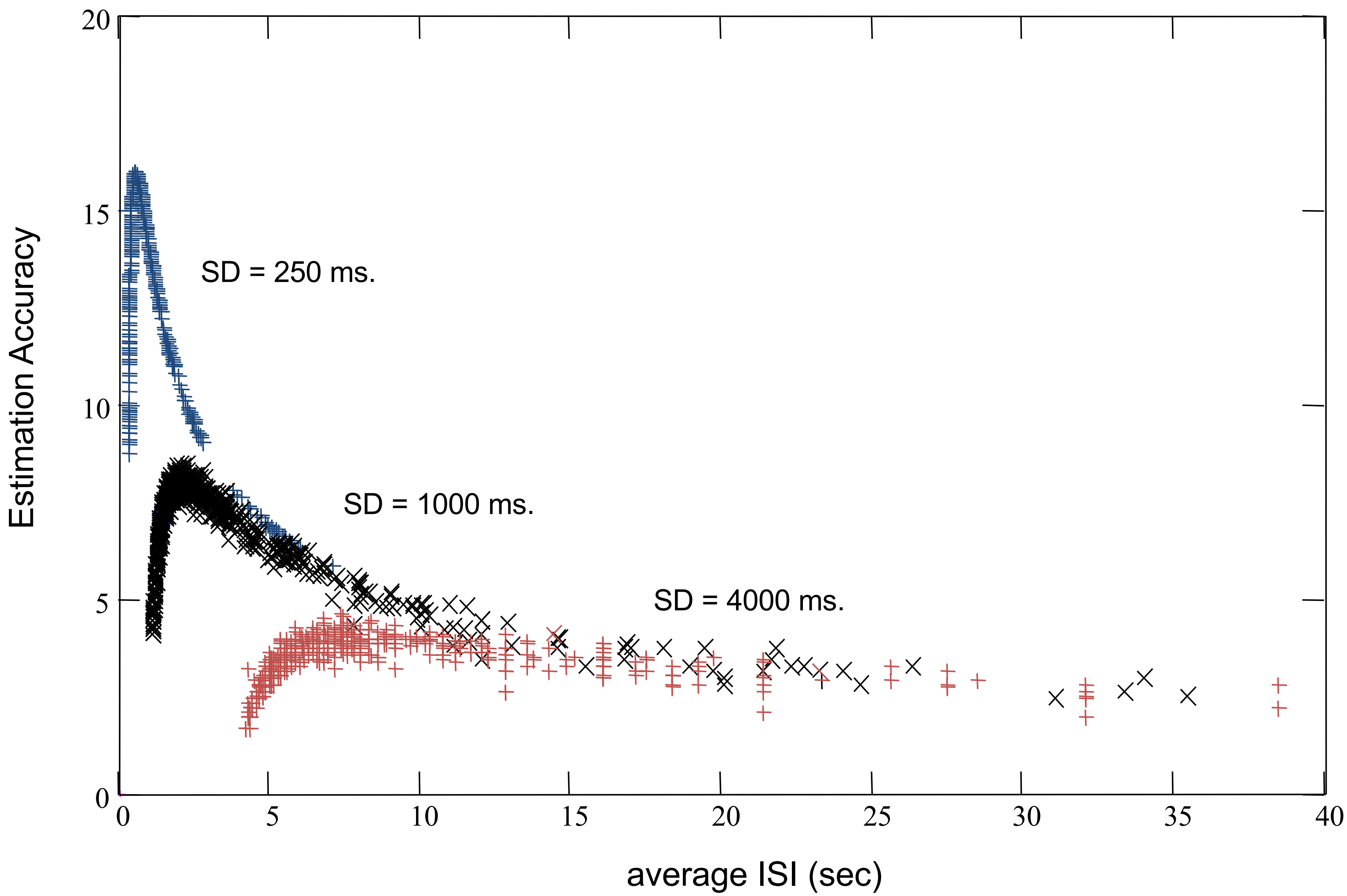
Received December 28, 2000

Detectability vs. Average ISI



R. M. Birn, R. W. Cox, P. A. Bandettini, Detection versus estimation in Event-Related fMRI: choosing the optimal stimulus timing. *NeuroImage* 15: 262-264, (2002).

Estimation accuracy vs. average ISI



R. M. Birn, R. W. Cox, P. A. Bandettini, Detection versus estimation in Event-Related fMRI: choosing the optimal stimulus timing. *NeuroImage* 15: 262-264, (2002).

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- Zoomed EPI
- Multiband excitation
- Low flip angle

Contrast Weighting

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- Asymmetric Spin-Echo
- Arterial Spin Labeling
- VASO
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- High b Diffusion Weighting
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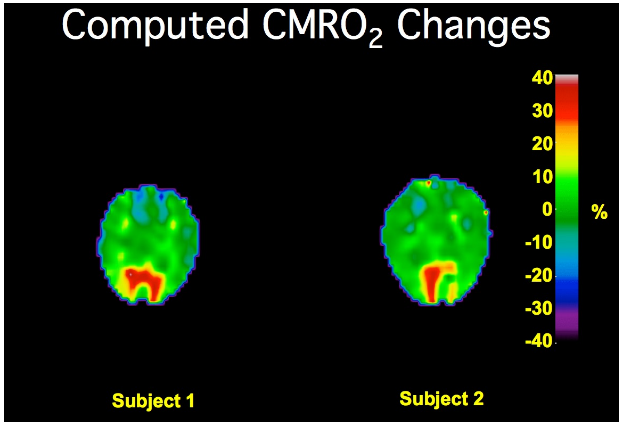
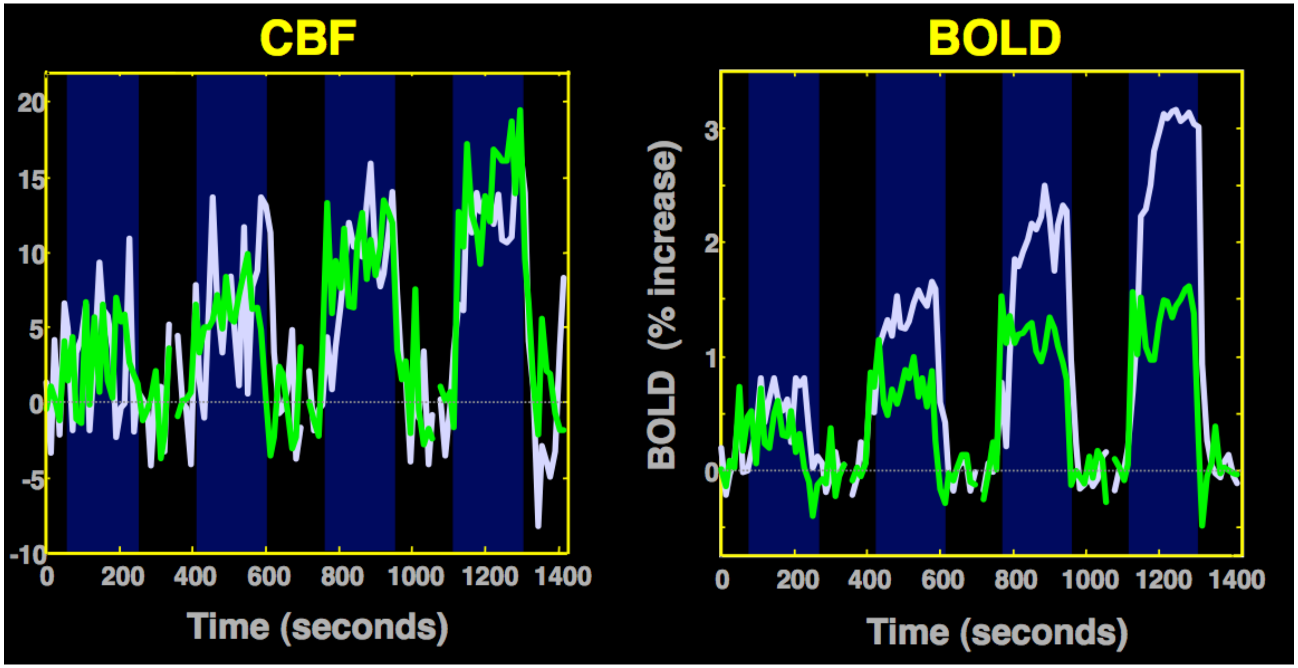
Calibration and Global Stressors



Activation-induced $CMRO_2$ changes

-requires a global hemodynamic stress
-assumption is that $CMRO_2$ unchanged with global stress
-requires simultaneous flow and BOLD collection

R. D. Hoge, et al, PNAS 96: 9403-9408, 1999



Visual = green
Hypercapnia = white

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Vessel identification and masking

-dark dots
-percent signal change upper limit
-standard deviation of phase and magnitude
-hemodynamic latency

Pros:

Will remove larger veins and perhaps some temporal and spatial variability

Cons:

Take a bit of extra processing
At low resolution, we like veins as they amplify the signal.

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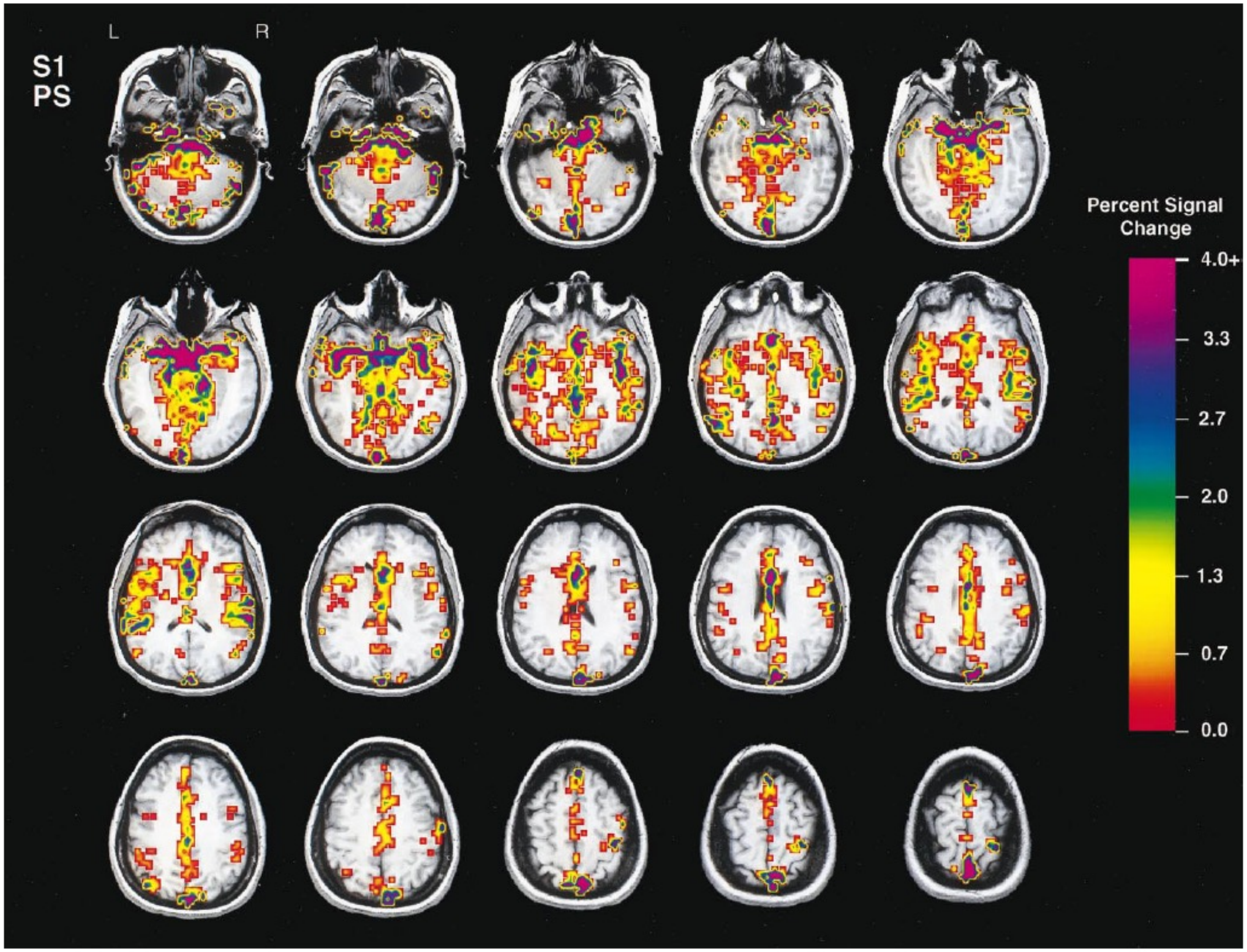
Data – based Cardiac Noise Removal



Dagli, et al. NeuroImage, 9, 407-415 (1999)

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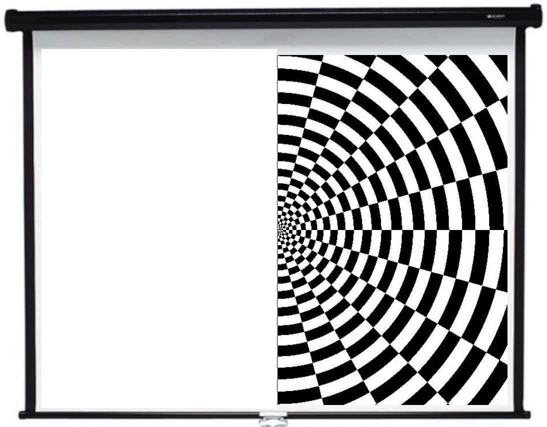
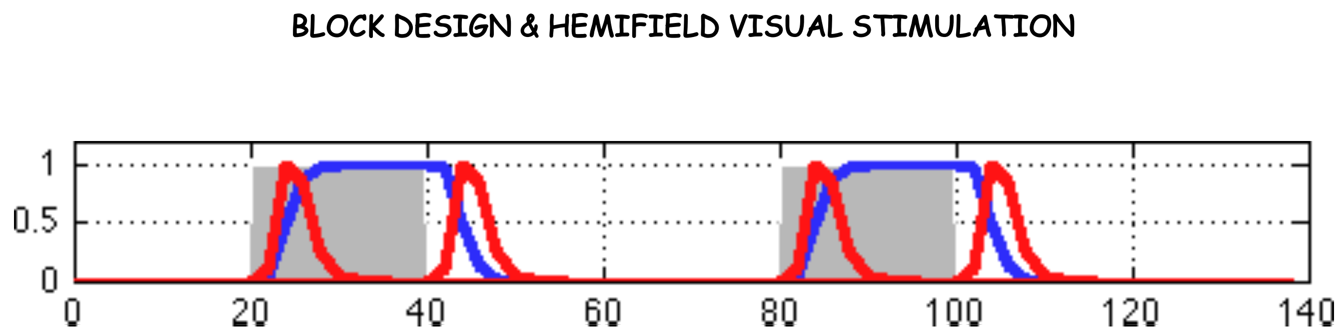
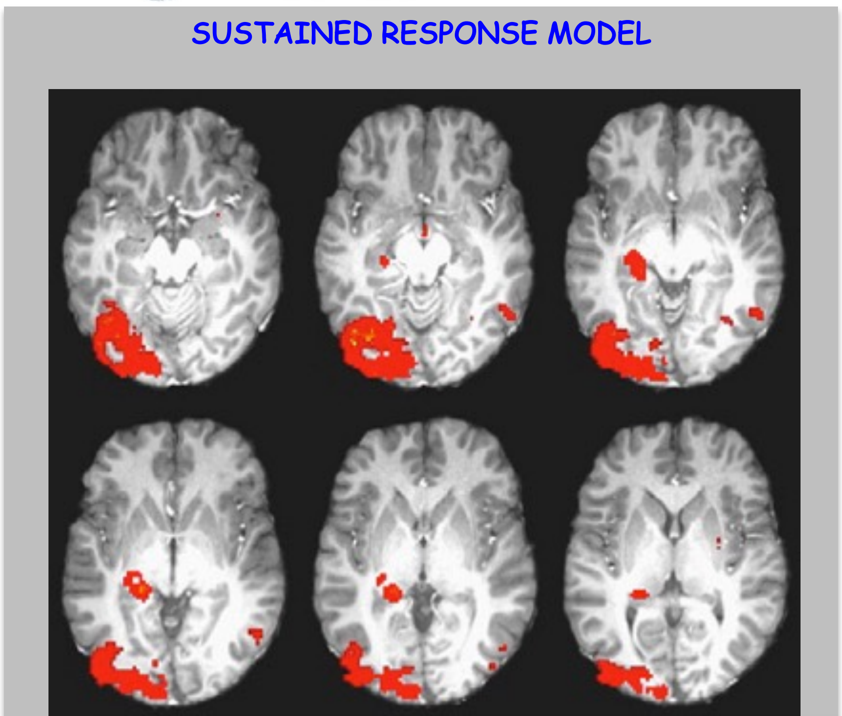
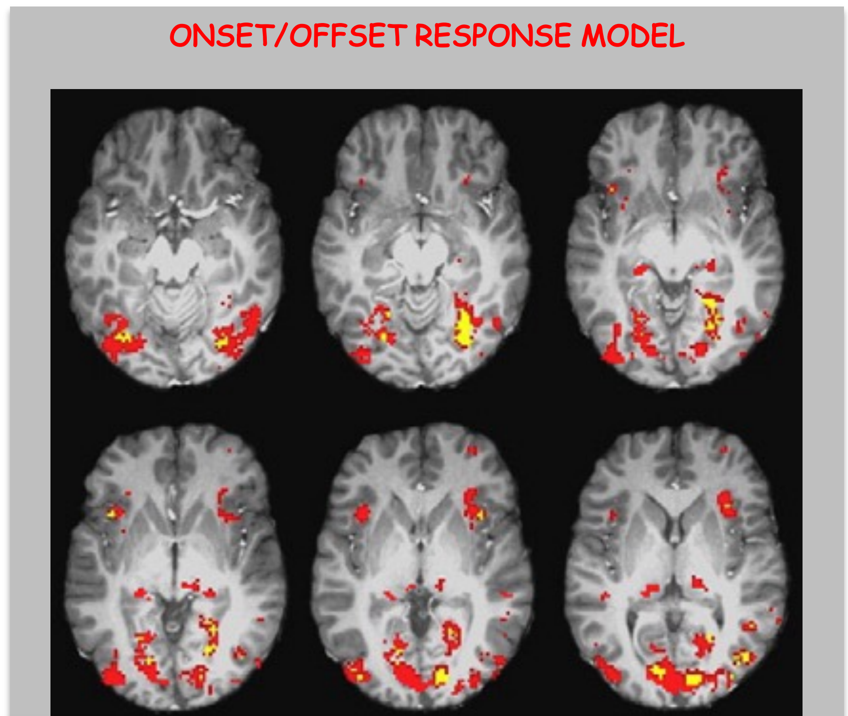
Using transients as regressors also.









DIFFERENT RESPONSE SHAPES ARE PRESENT ACROSS DIFFERENT REGIONS OF THE BRAIN FOR A SINGLE STIMULUS TYPE

Uludag et al. Magn Reson Imaging. 2008 Sep;26(7):863-9.

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