fMRI Methods That Have Not Caught On

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&

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http://fmrif.nimh.nih.gov


Le Medecin guarissant Phantasie
Purgeant aussi Par drogues la folie.

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
- calibration or global stressors
- vessel identification and masking (standard deviation, dark dots, latency…)
- noise regression from regions in brain (sagittal sinus, etc..)
- Modeling also the transients.
- Phase shifting reference functions
- latency mapping/modulation
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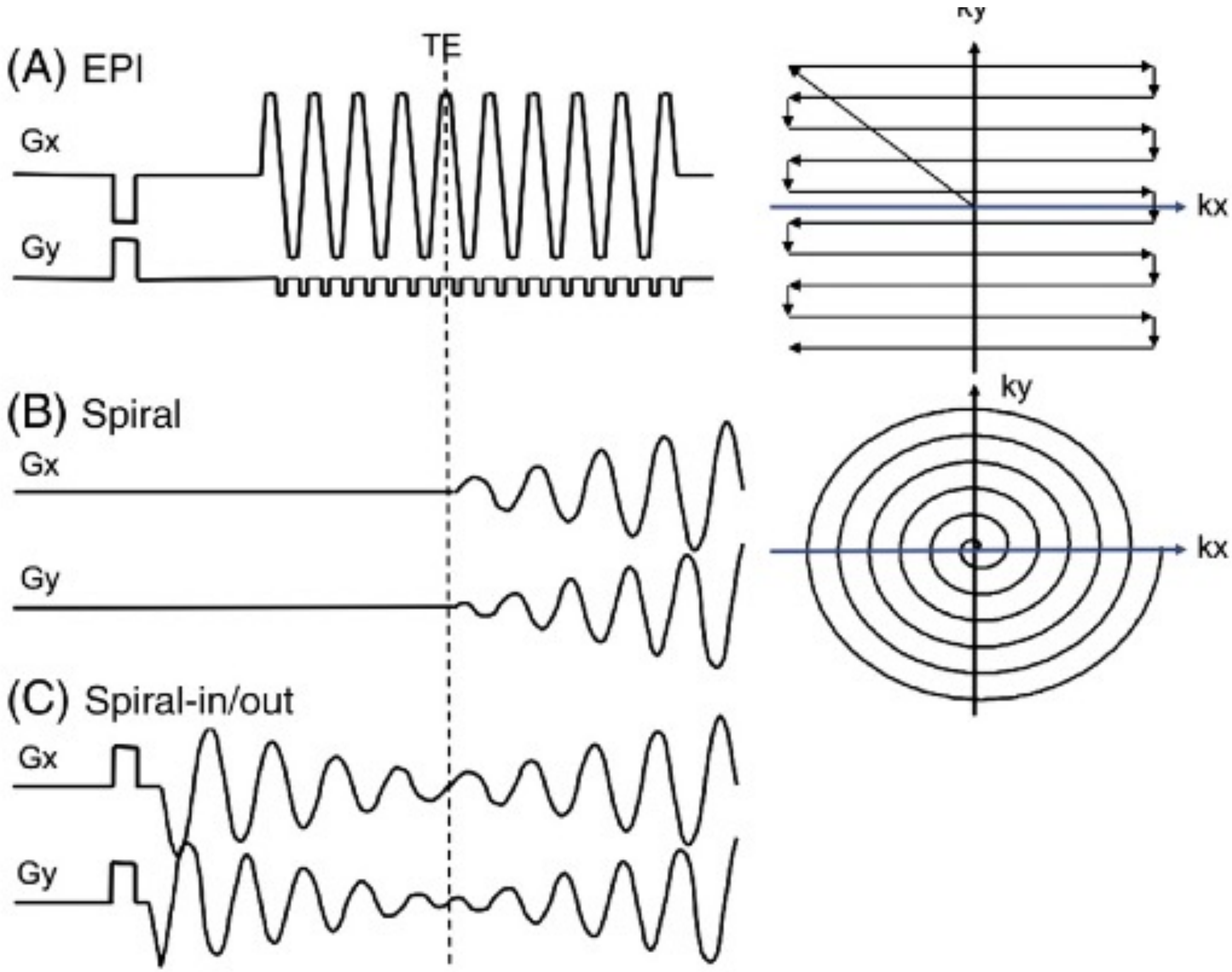
Spiral Scanning



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

Spiral Scanning

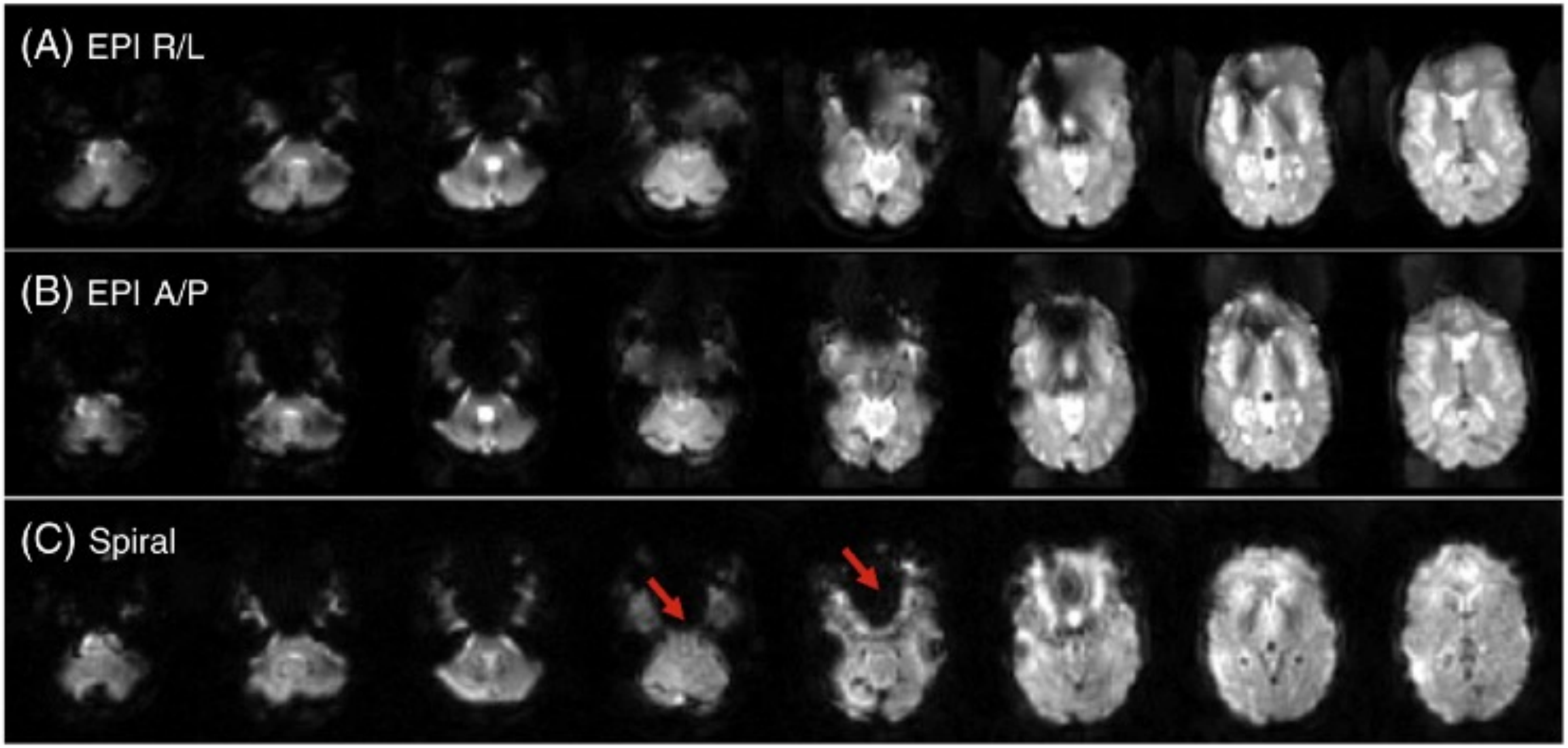
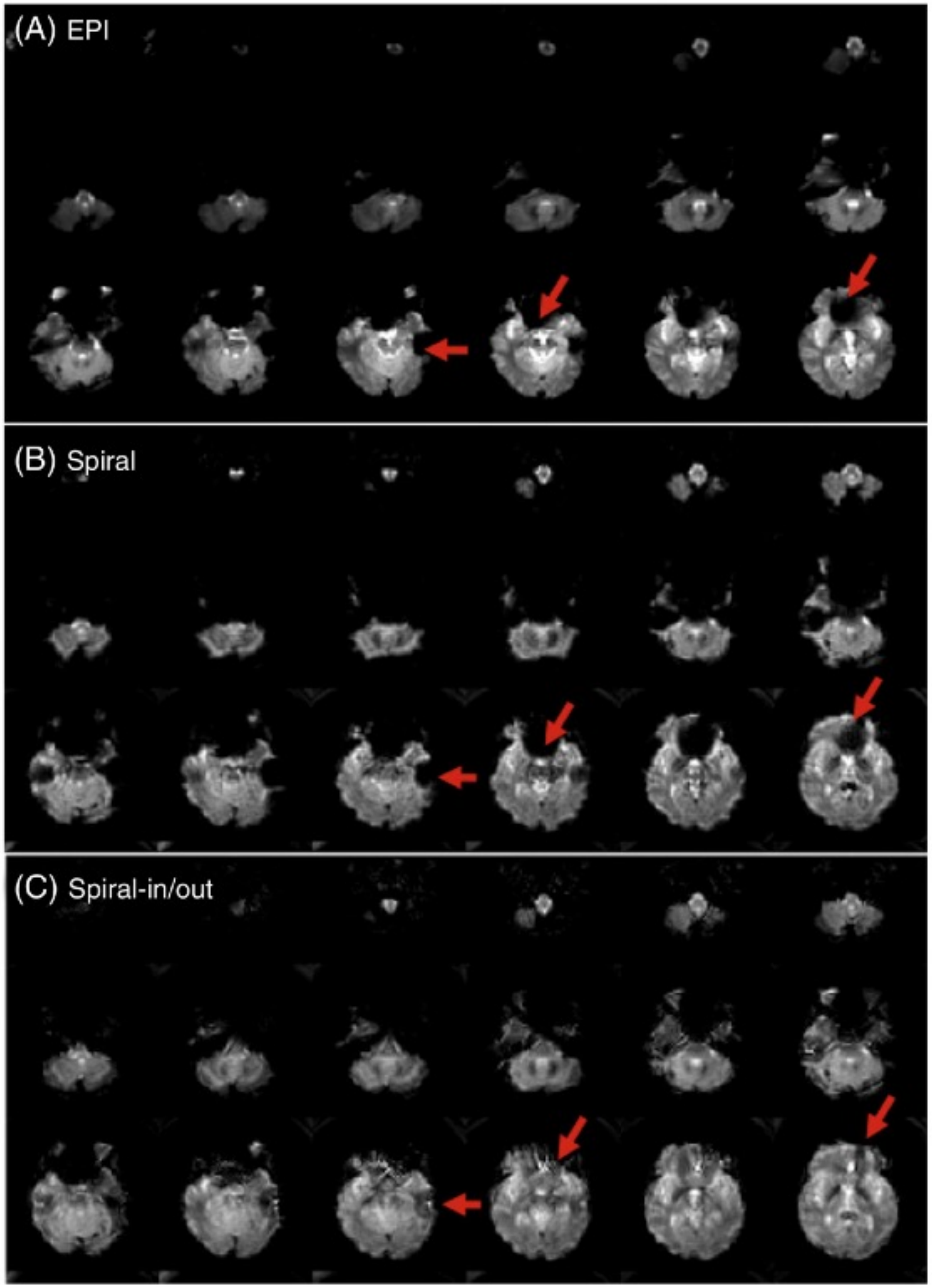


Fig. 3. EPI images with phase encoding direction R/L (A) or A/P (B). Susceptibility-induced field gradients (SFGs) cause geometric distortion along the phase encoding direction. With spiral (C), SFGs instead cause blurring. Note that there is increased signal in most slices with spiral, but loss in several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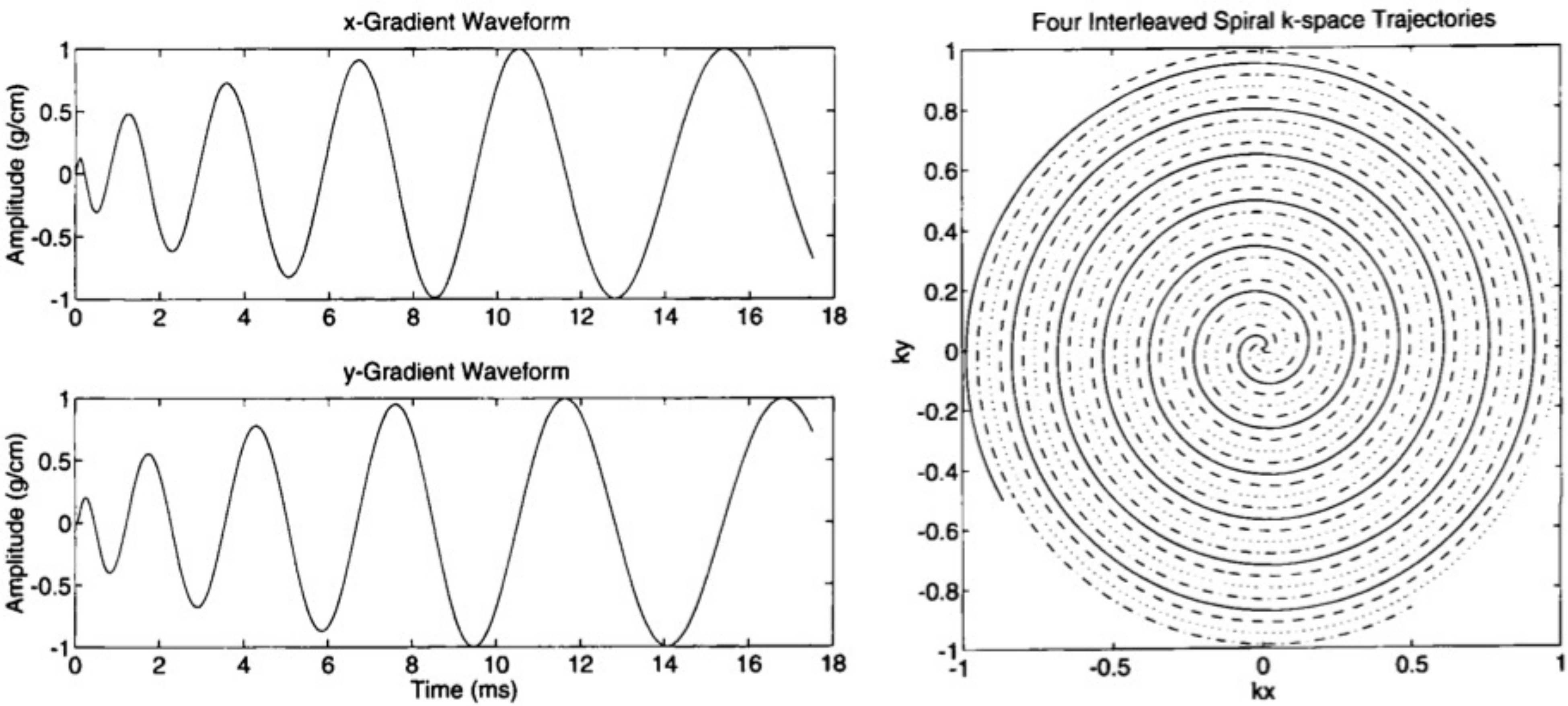
Multi-Shot Spiral

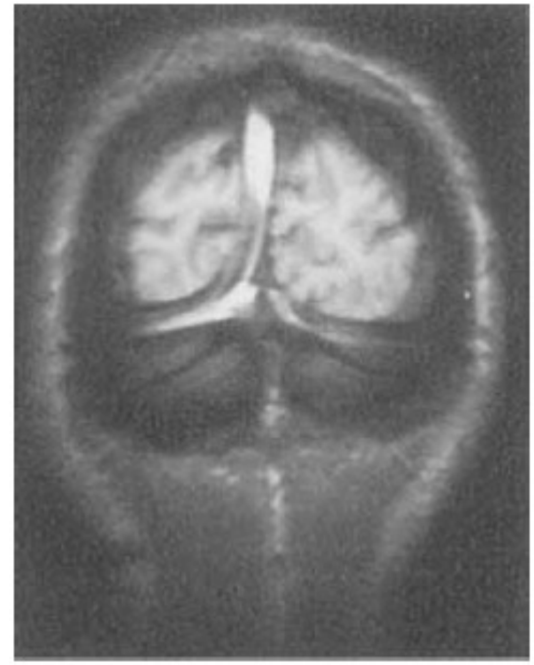


a. **b.**

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

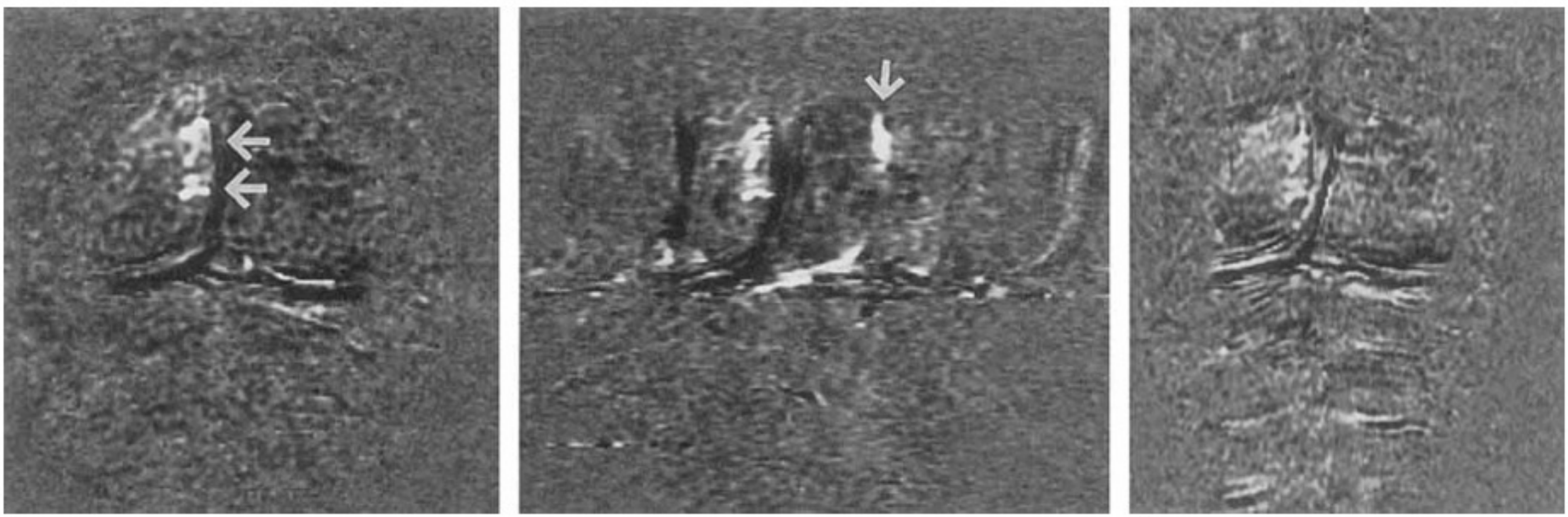
D. Noll et al, JRMI 5:49-56 (1995)

For multi-shot EPI (another technique that has not caught on), Spiral works better than multi-shot standard rastering.



a.

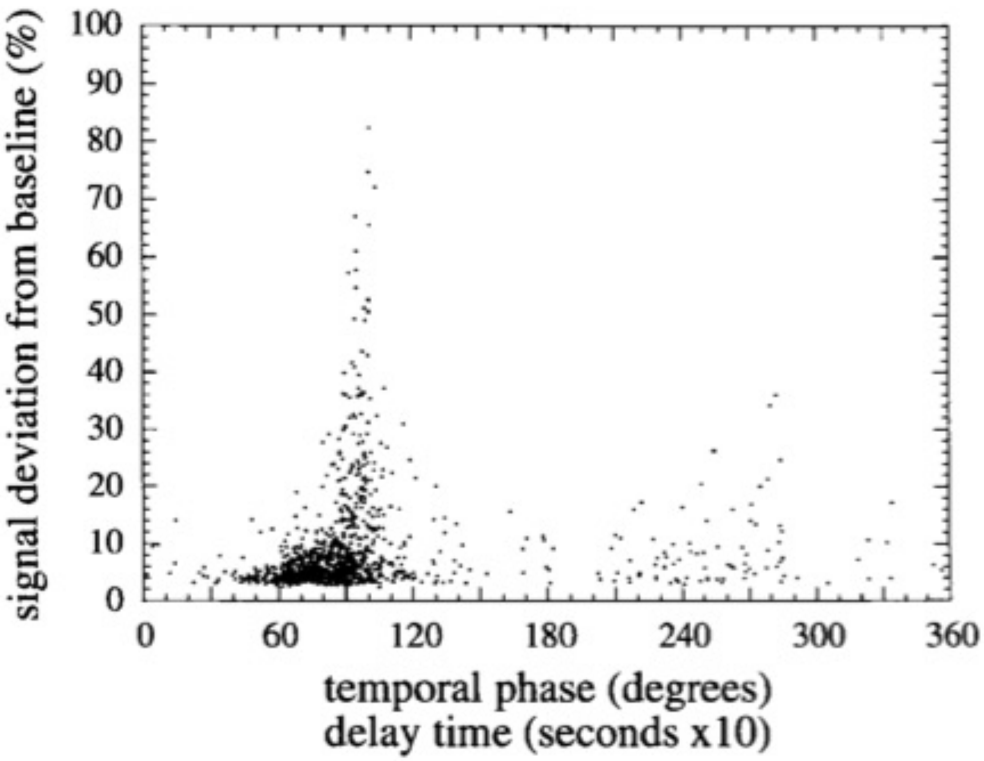
Figure 3. Activation in primary visual cortex with a single character in the visual field. **(a)** T1-weighted image of coronal section near occipital pole. **(b–d)** Average difference images obtained with **(b)** spiral k-space acquisition, **(c)** 2DFT with left-to-right phase encoding, and **(d)** 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.**

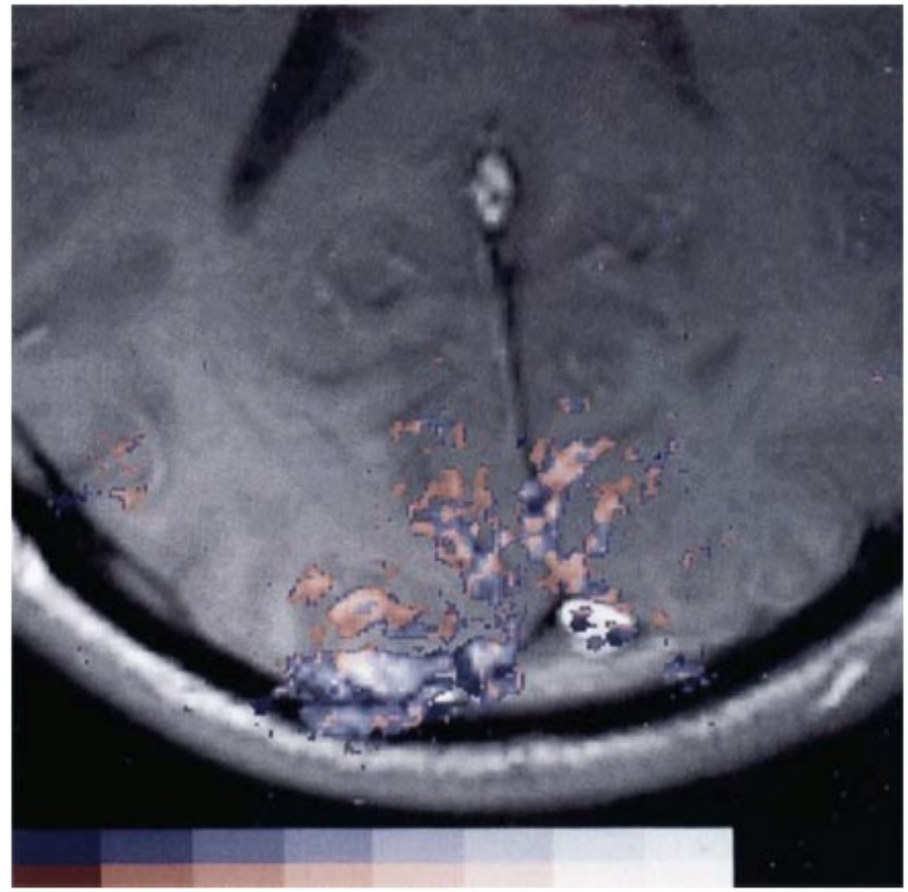


b. **c.** **d.**

Spiral

Multi-Shot Spiral – latency mapping





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

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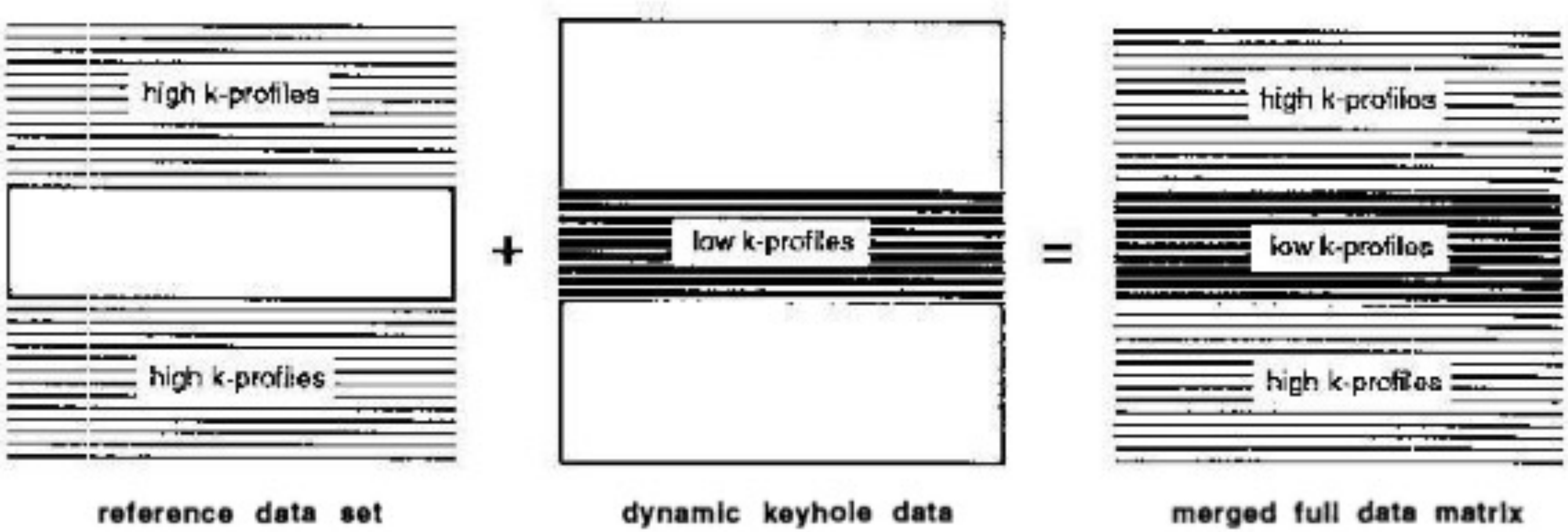
Keyhole imaging



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

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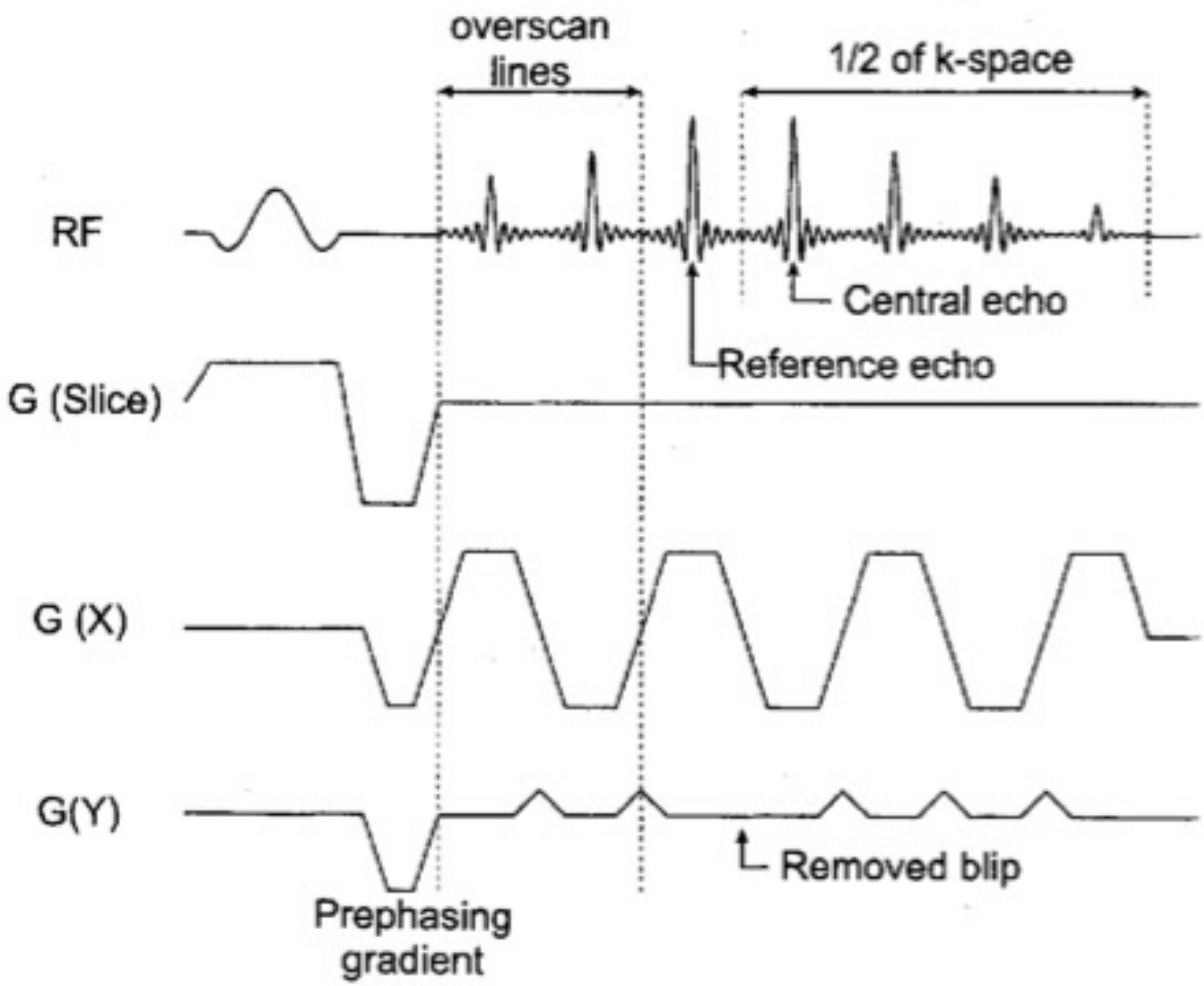
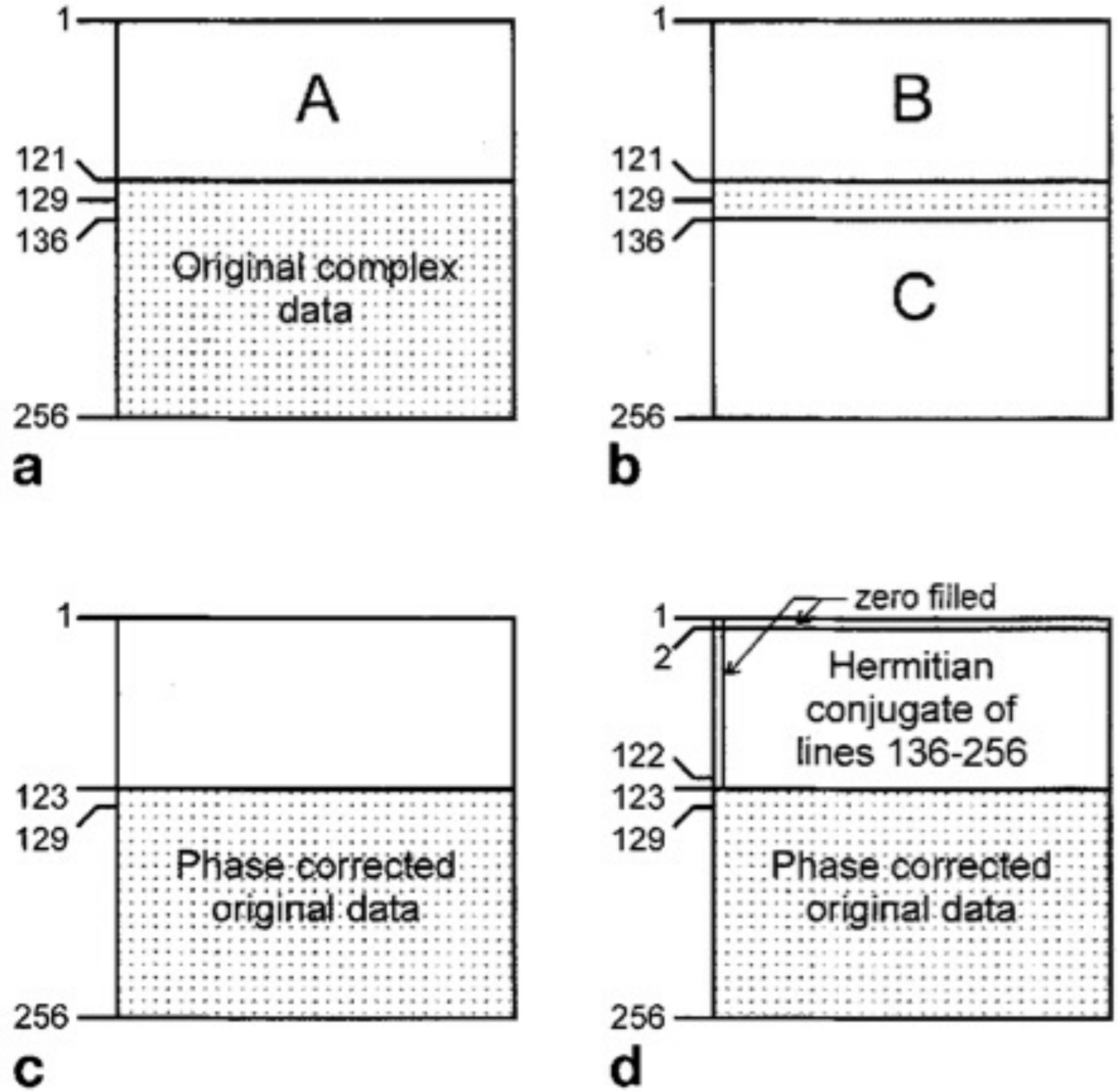
Partial k-space reconstruction



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

Partial k-space reconstruction



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

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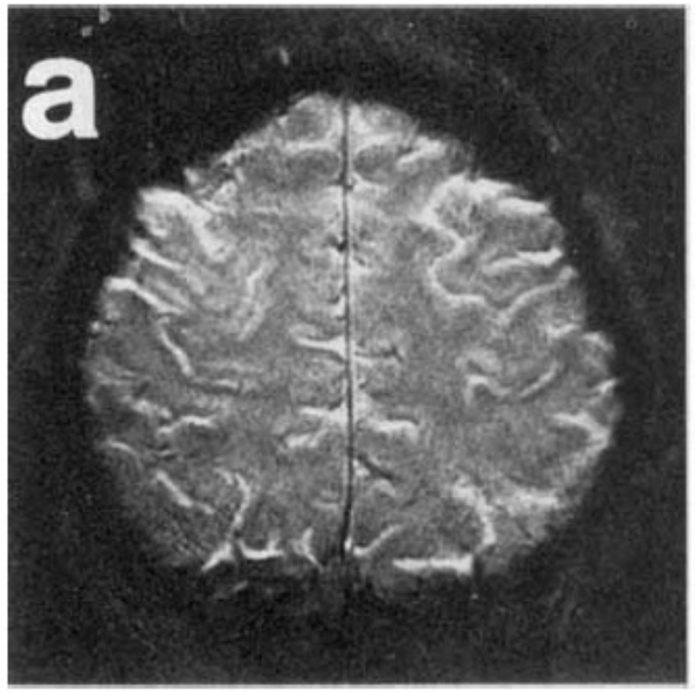

Echo and Readout Times (ms)

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)

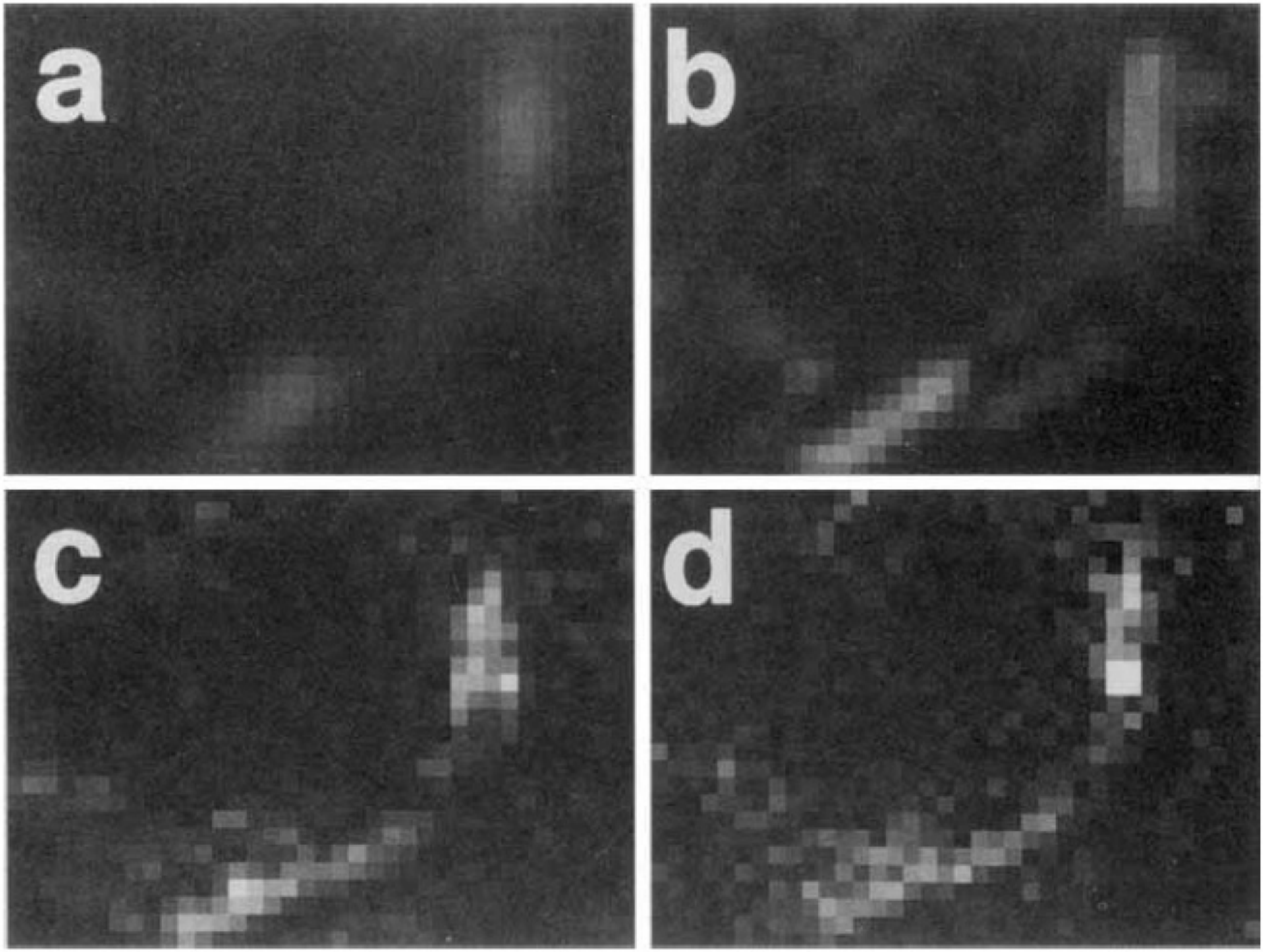

FIG. 9. Percent change maps of the right motor cortex. Slice width was 5 mm, and the FOV was 16 cm. Image matrix sizes and corresponding voxel sizes were: (a) 64 × 64 and 2.5 mm^2; (b) 128 × 128 and 1.25 mm^2; (c) 192 × 192 and 0.83 mm^2; (d) 256 × 256 and 0.62 mm^2. TE was 20 ms for each image, and 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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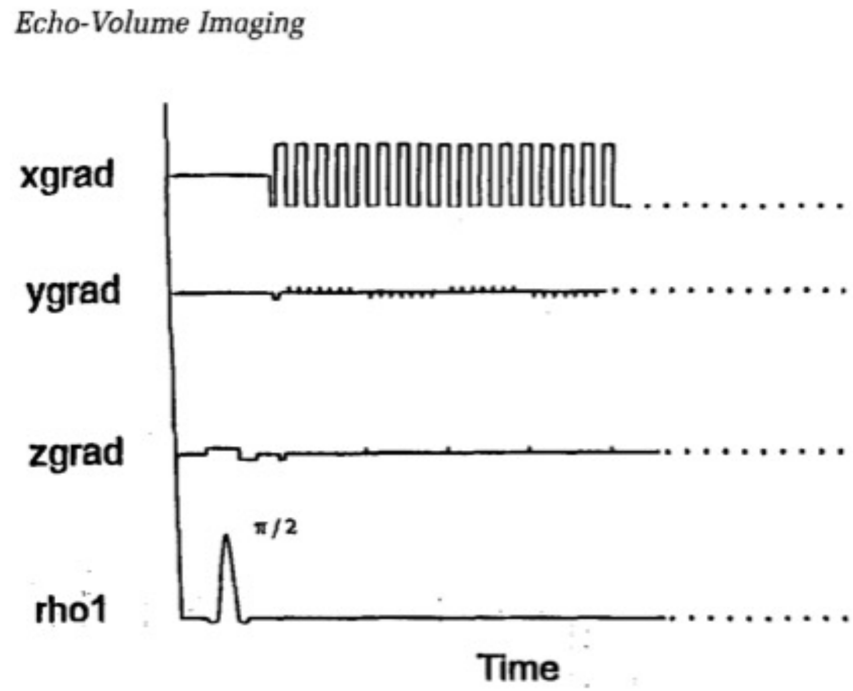
Echo Volume Imaging



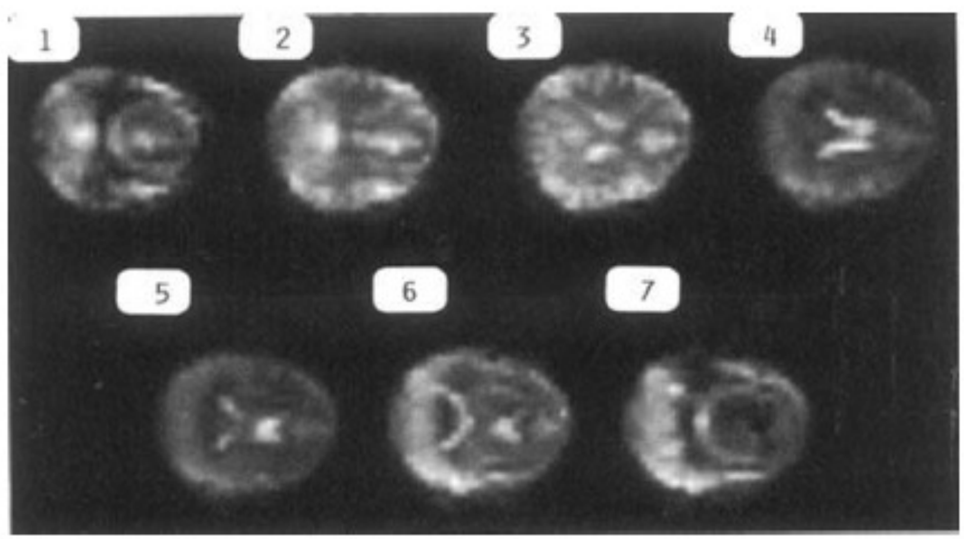


FIG. 3. Single-echo EVI human brain images. Images are taken with a FOV of 24 × 24 × 3.5 cm^3 and matrix of 32 × 32 × 7.

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

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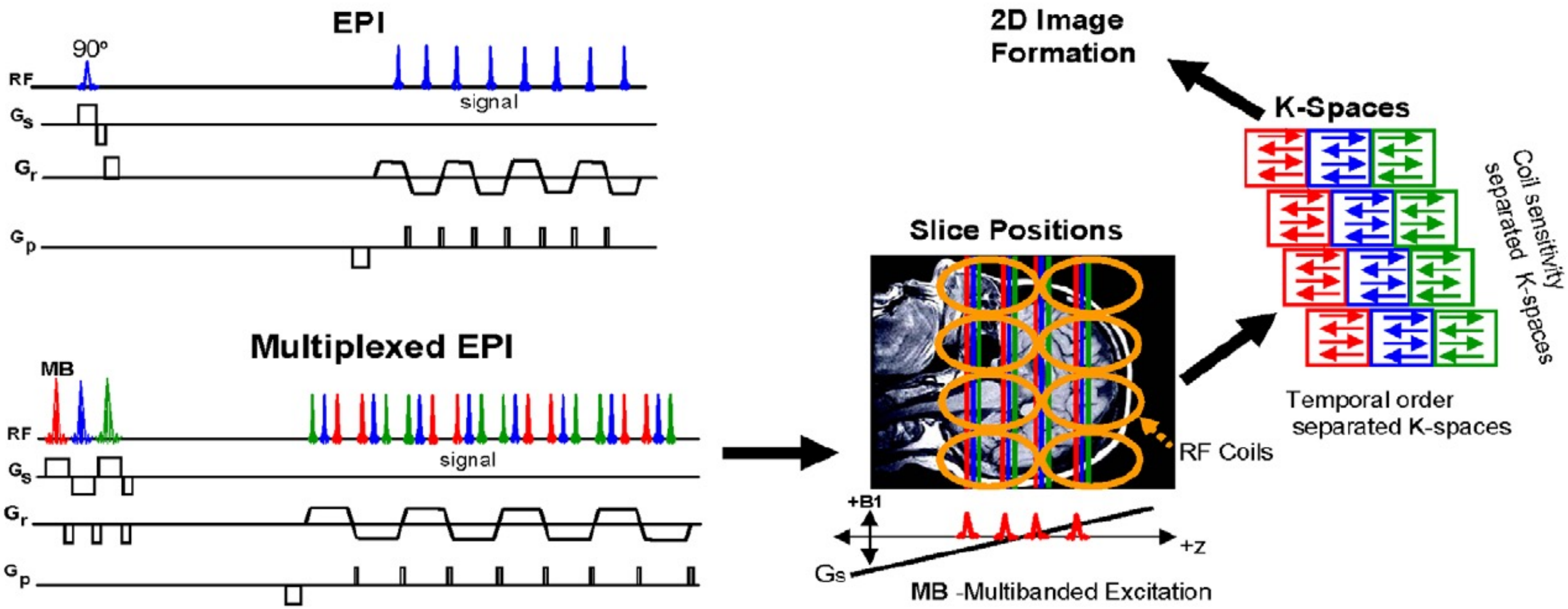
Multiband Excitation



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

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

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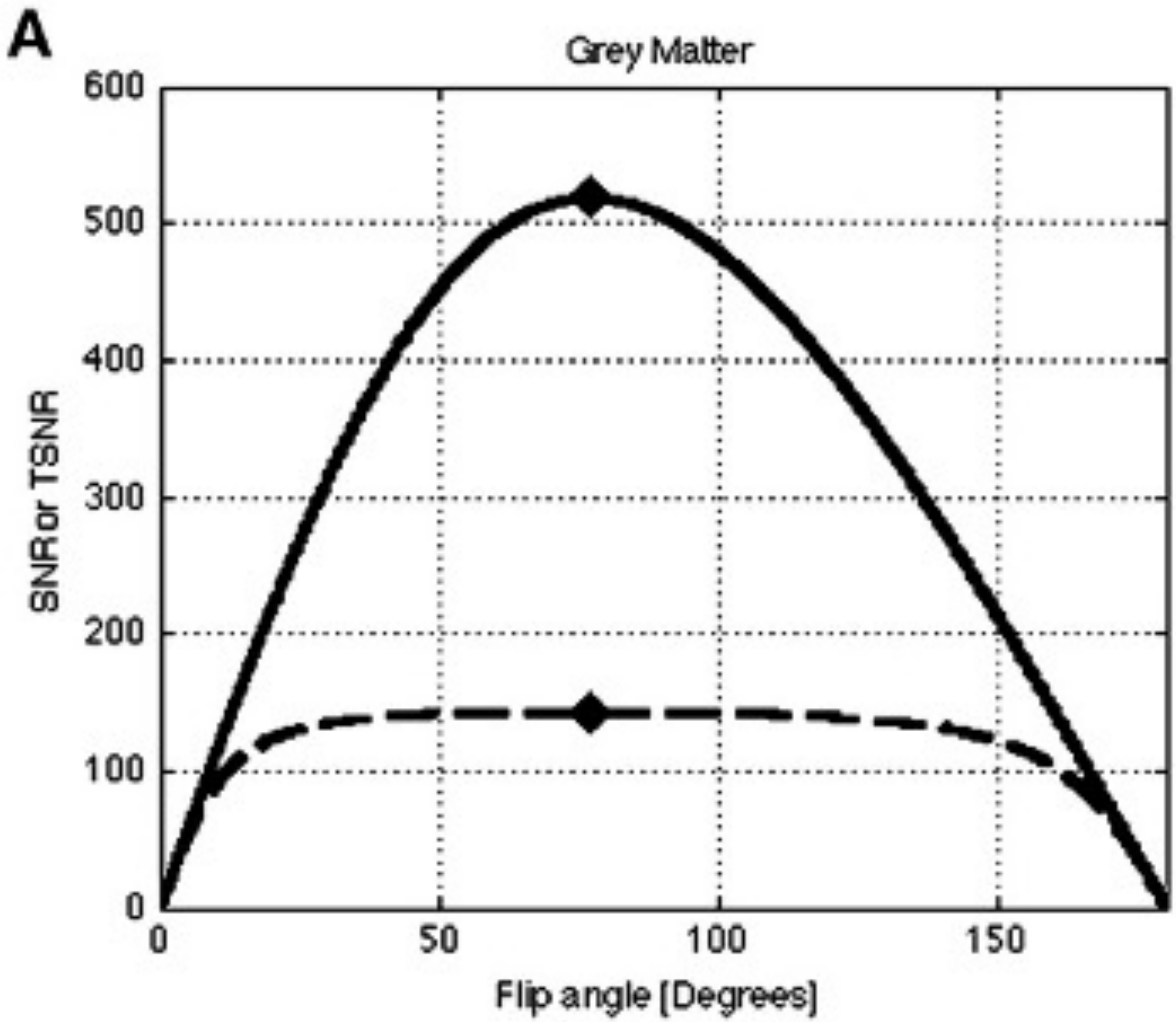
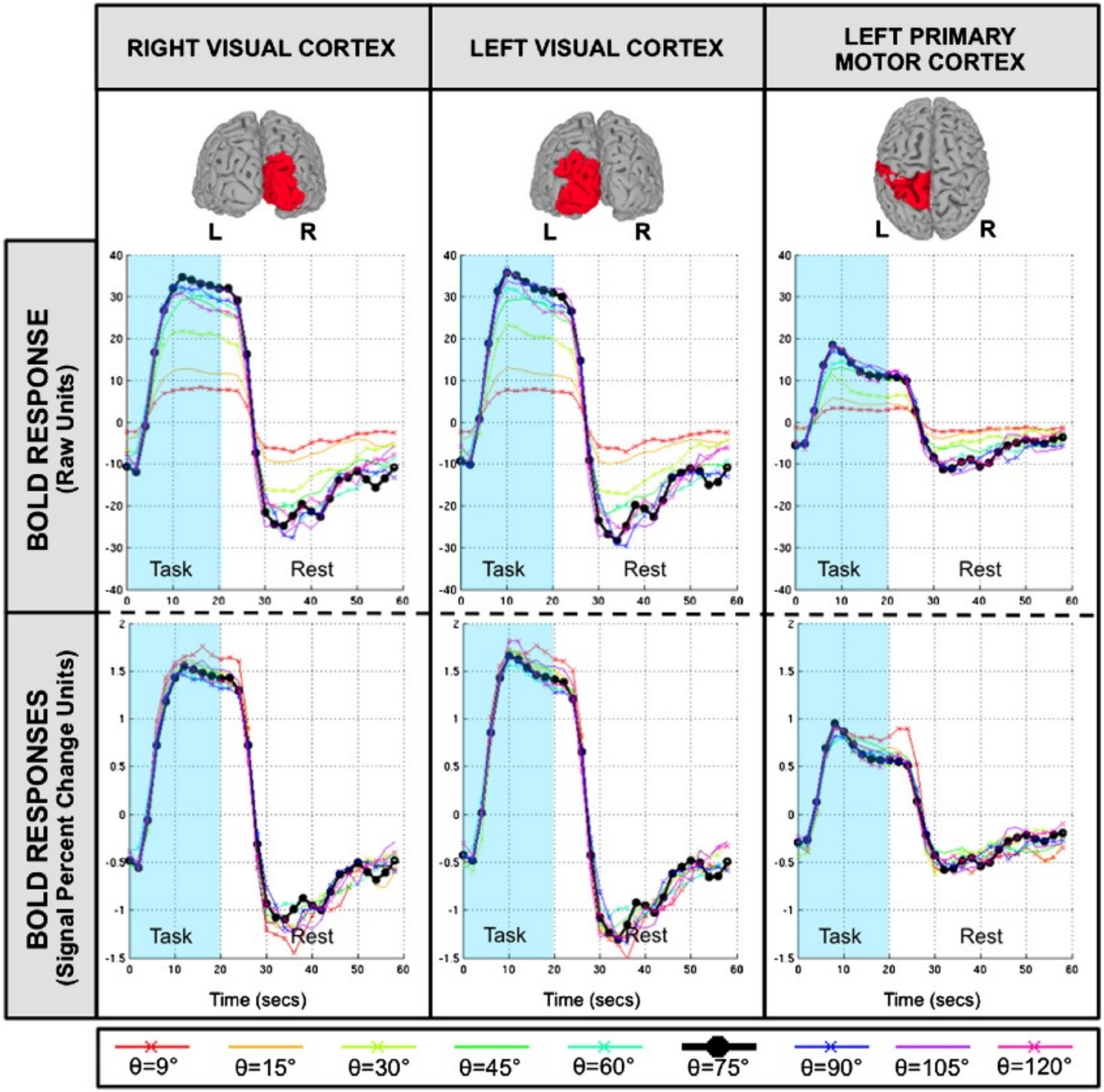
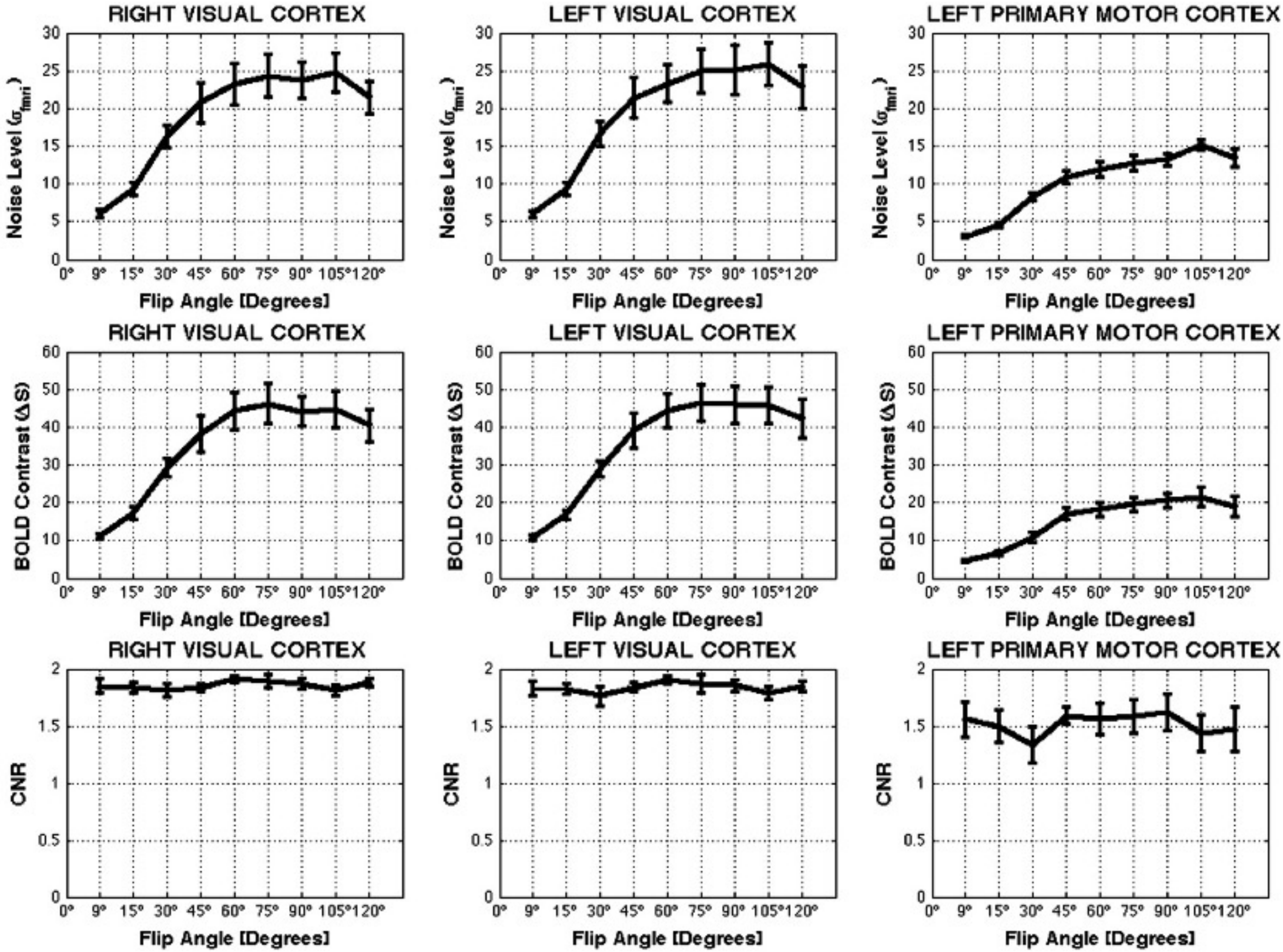
Low flip angle



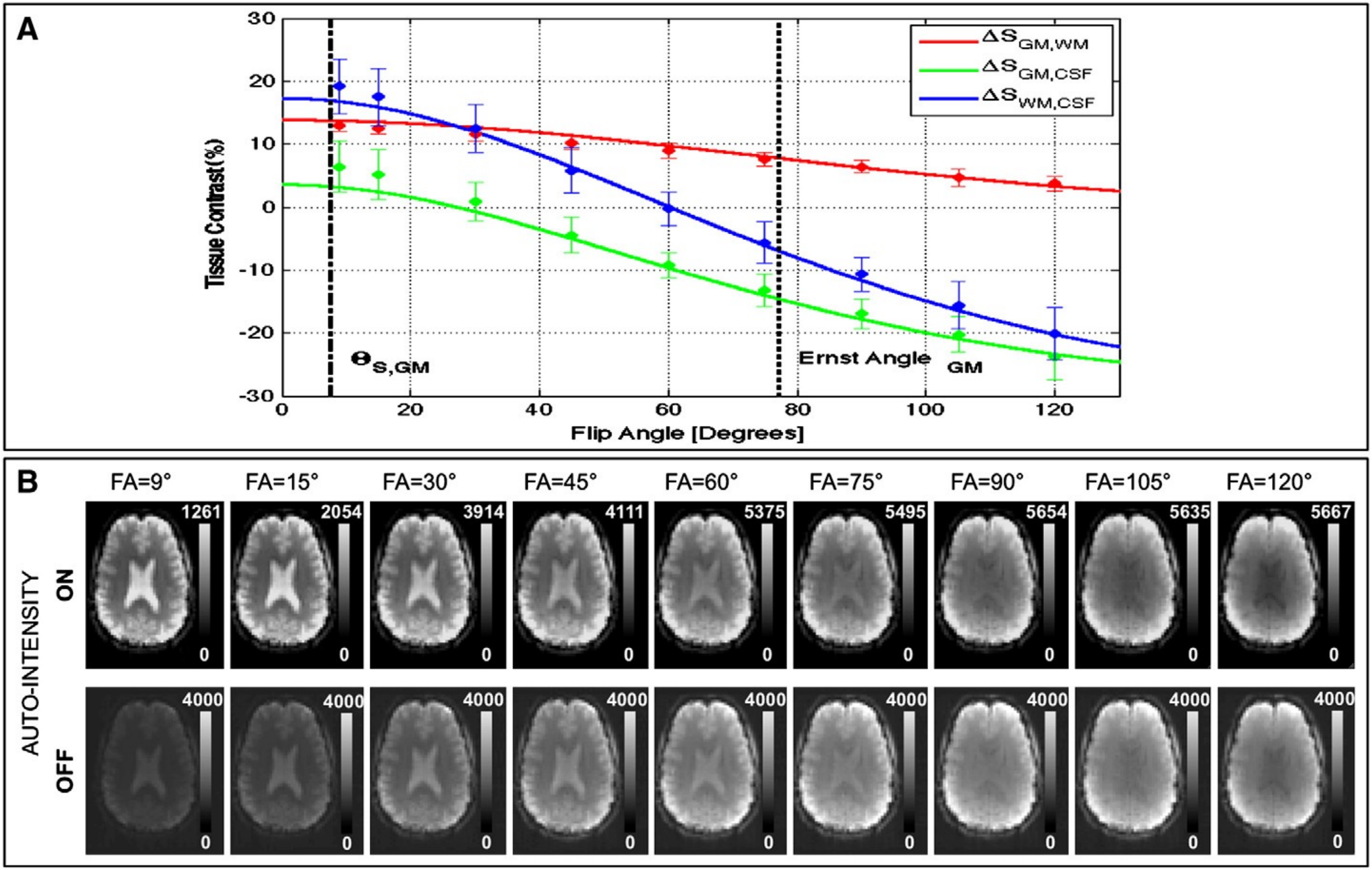
J. Gonzalez-Castillo, et al., NeuroImage, 54, 2764-2778 (2011)



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]


A
30
20
10
0
-10
-20
-30
Tissue Contrast (%)
0
20
40
60
80
100
120
Flip Angle [Degrees]
ΔS GM,WM
ΔS GM,CSF
ΔS WM,CSF
Θ S,GM
Ernst Angle GM
B
FA=9°
FA=15°
FA=30°
FA=45°
FA=60°
FA=75°
FA=90°
FA=105°
FA=120°
AUTO-INTENSITY
ON
OFF
1261
2054
3914
4111
5375
5495
5654
5635
5667
4000
0

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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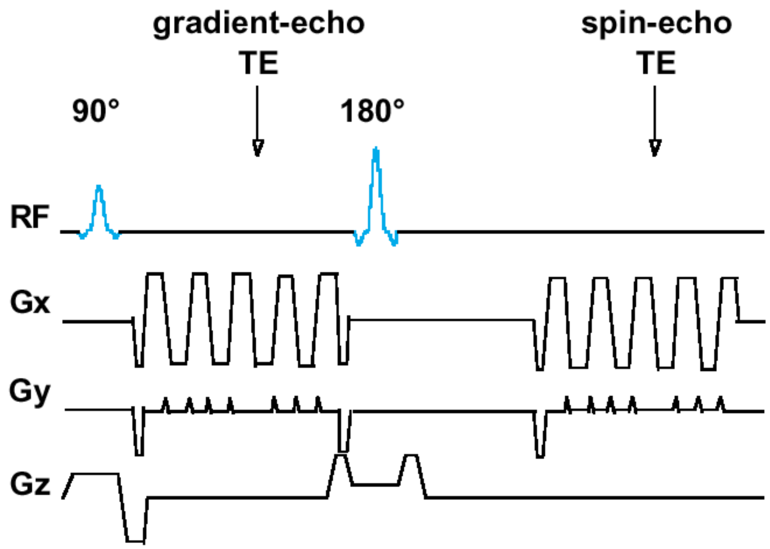
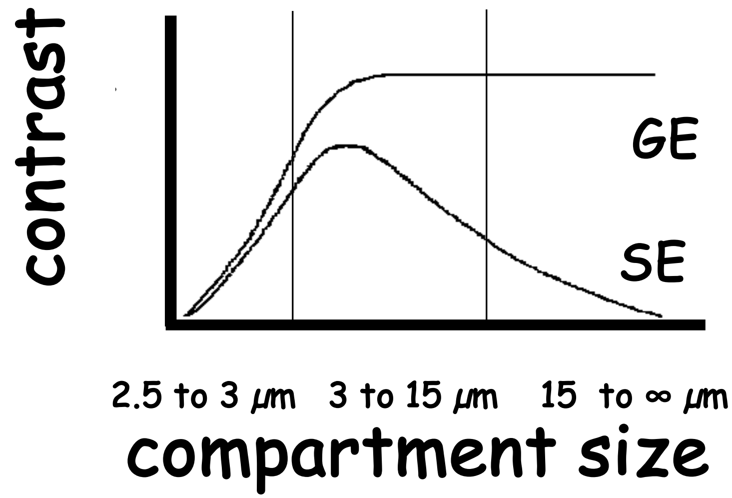
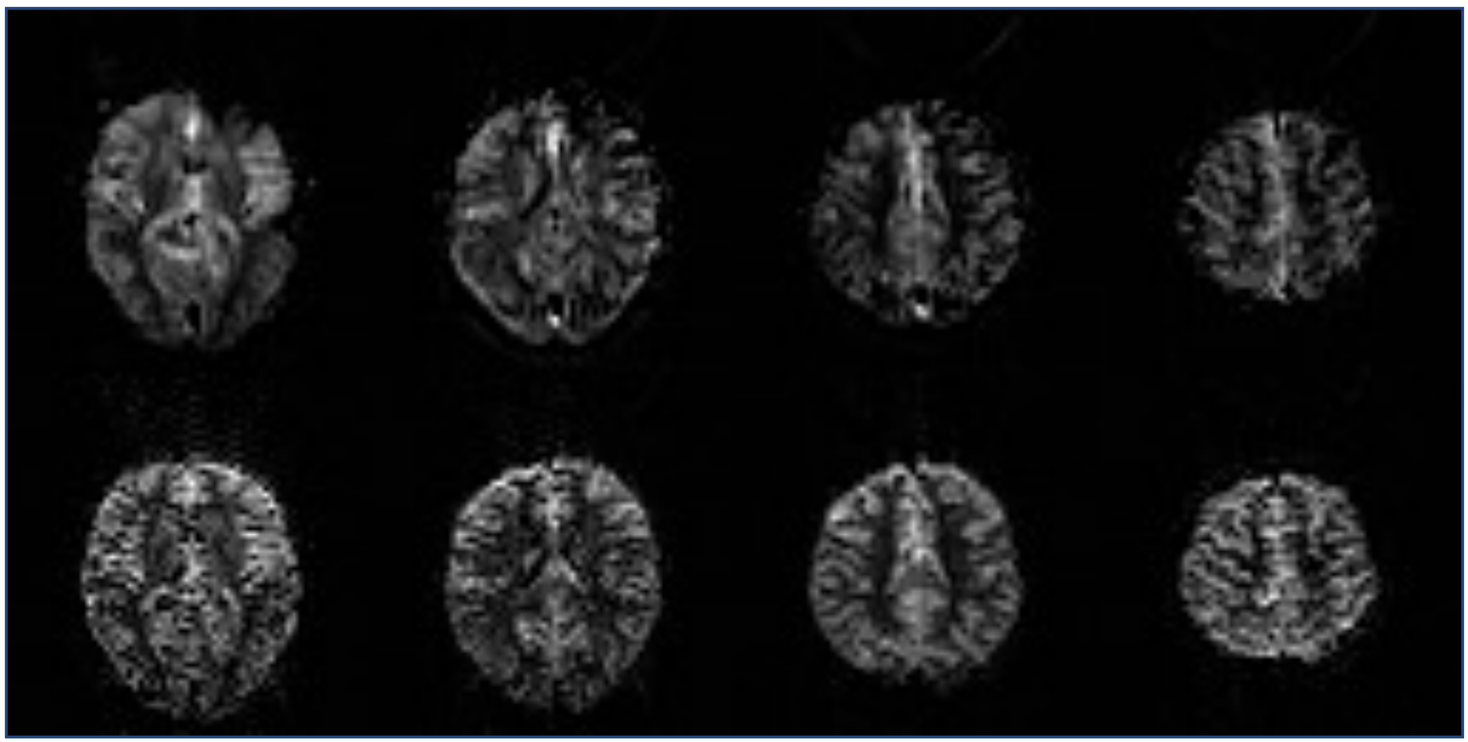
Spin-echo



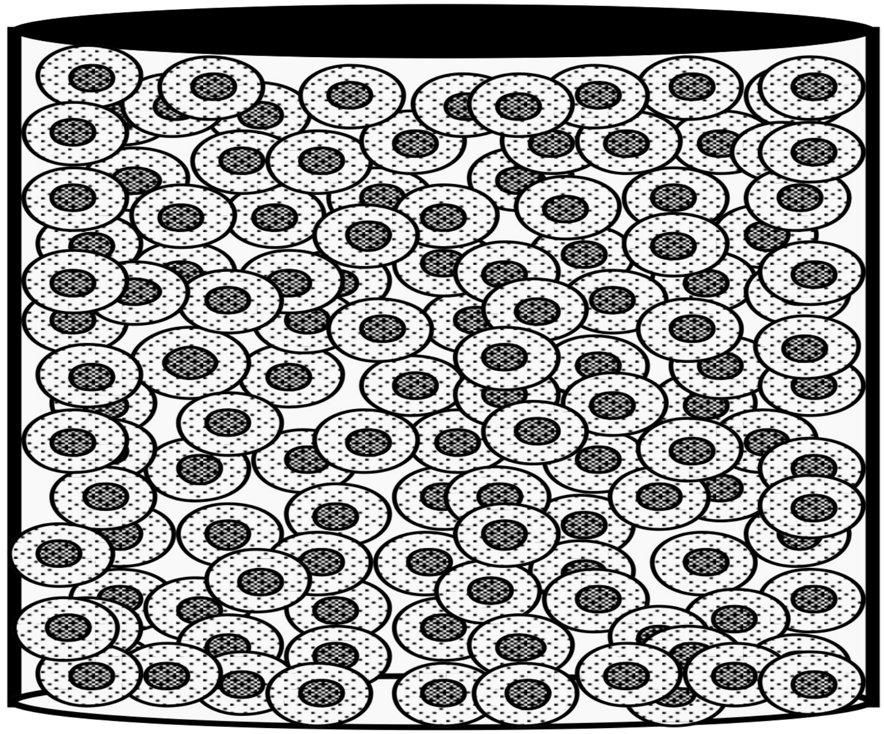


GE
TE = 30 ms

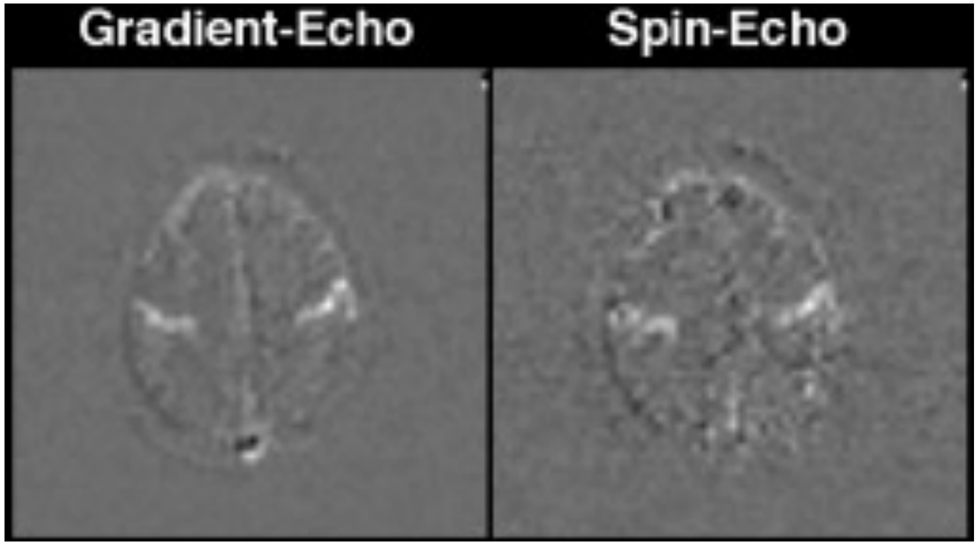
SE
TE = 110 ms

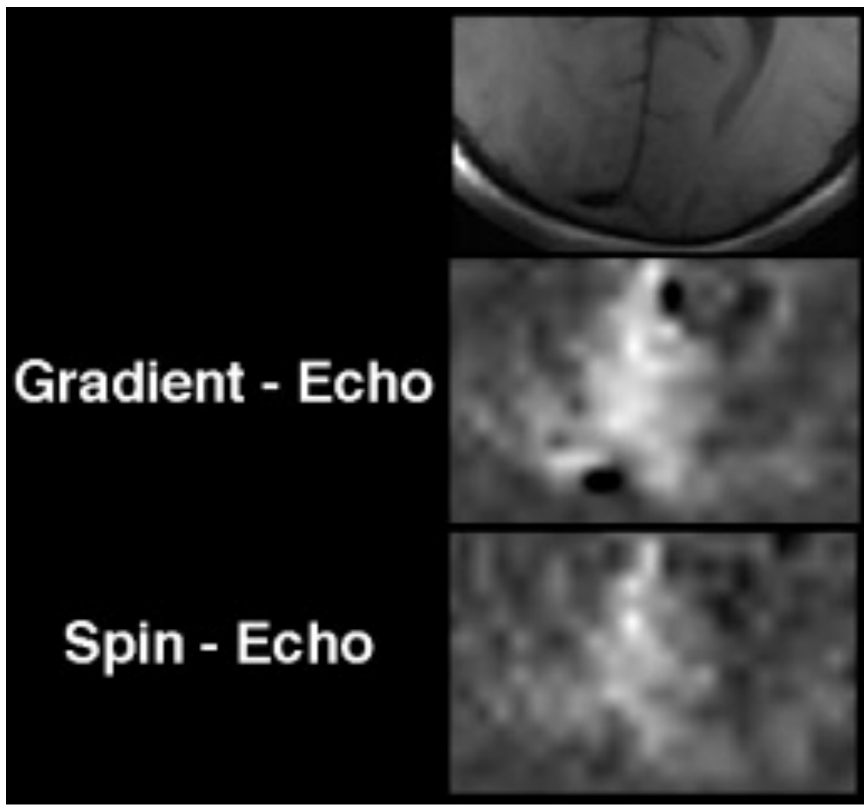


The Problem with Spin-Echo

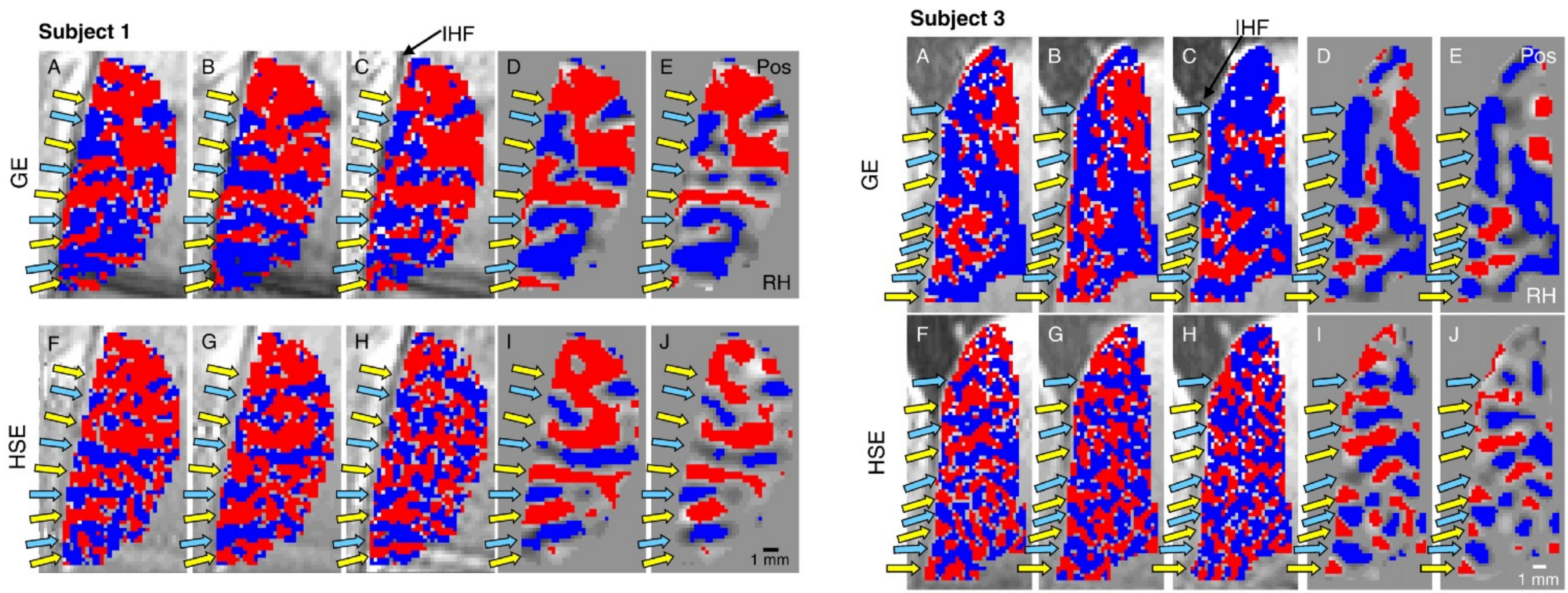


Spin-echo



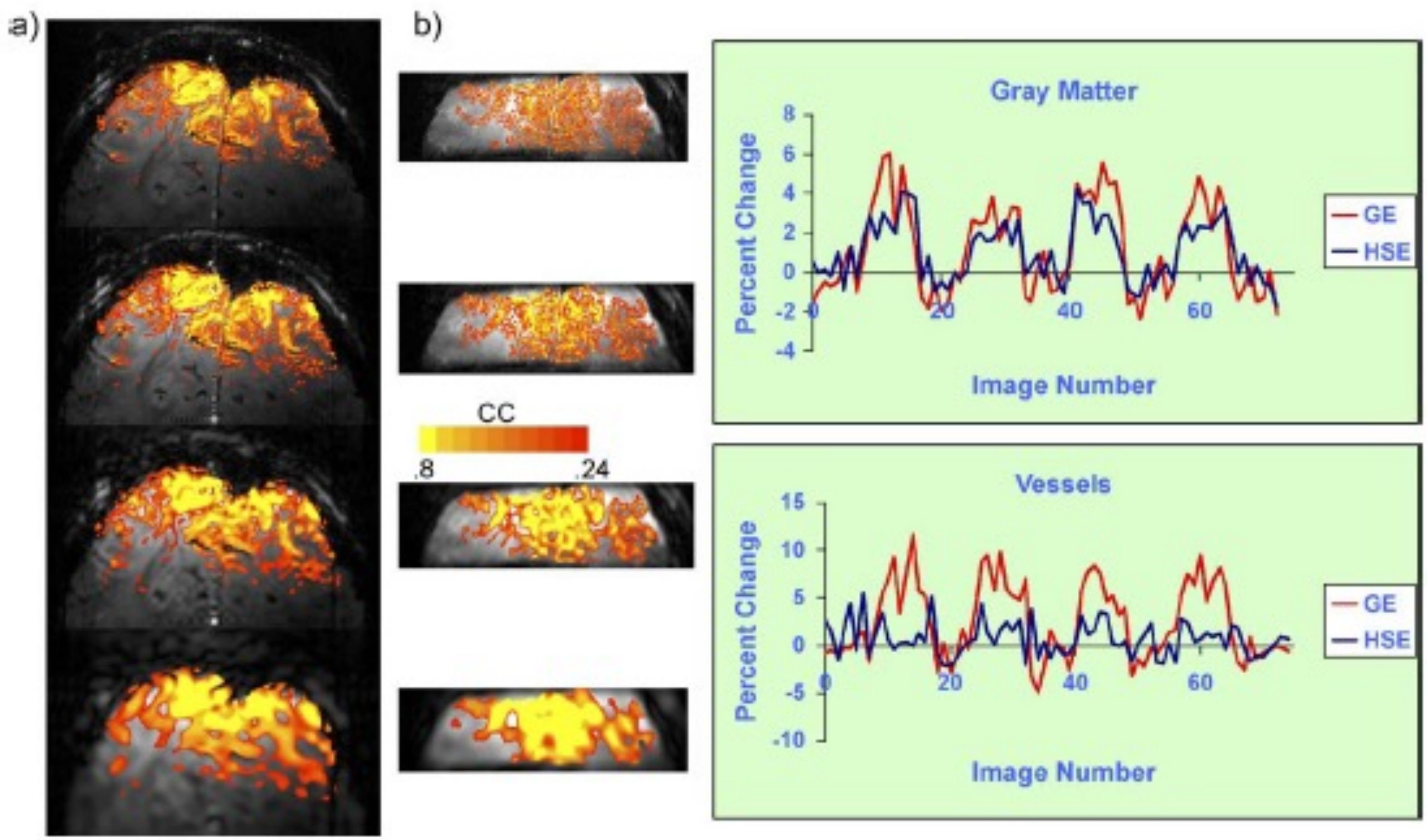


Spin-echo



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

Spin-echo



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

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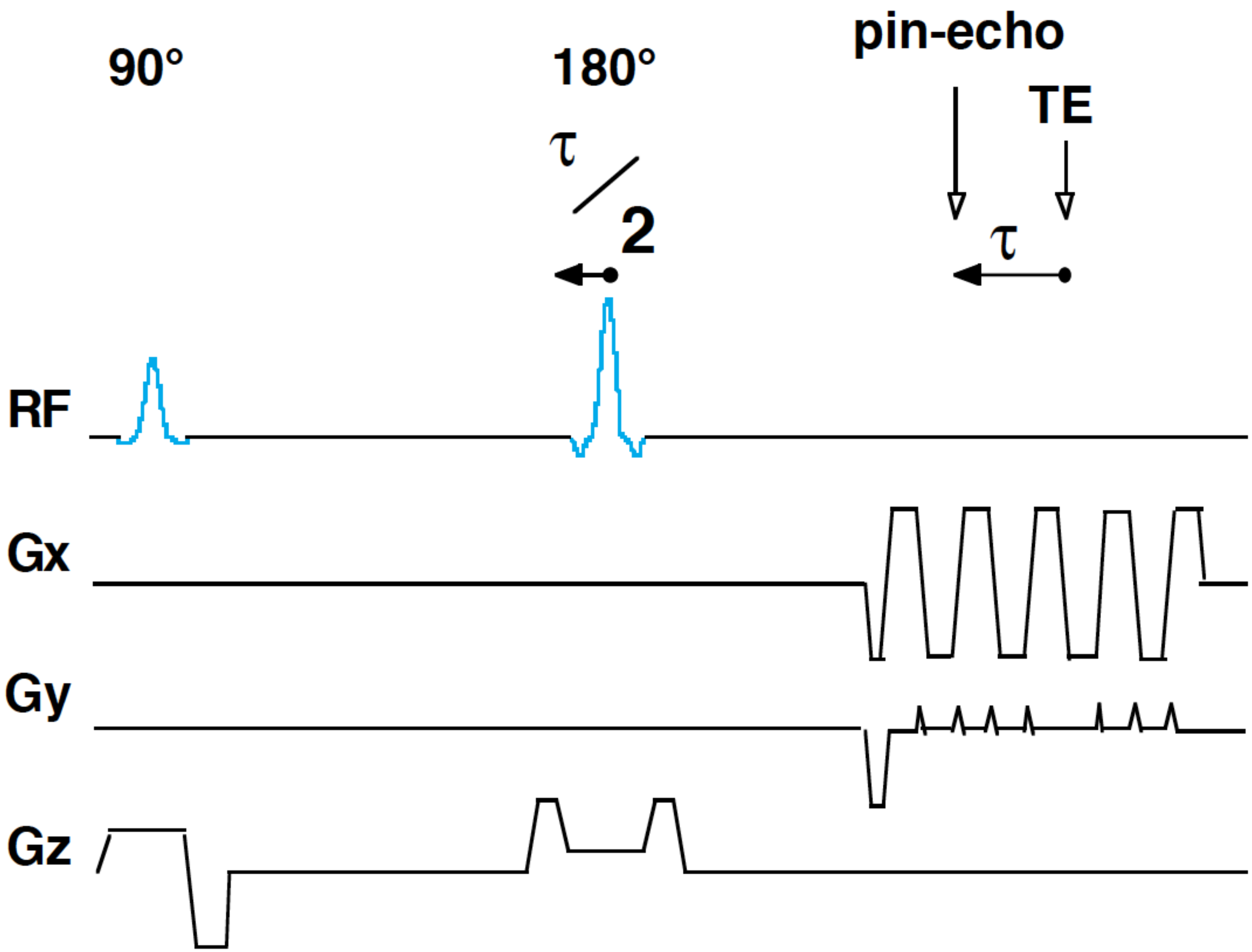
Assymetric Spin-echo



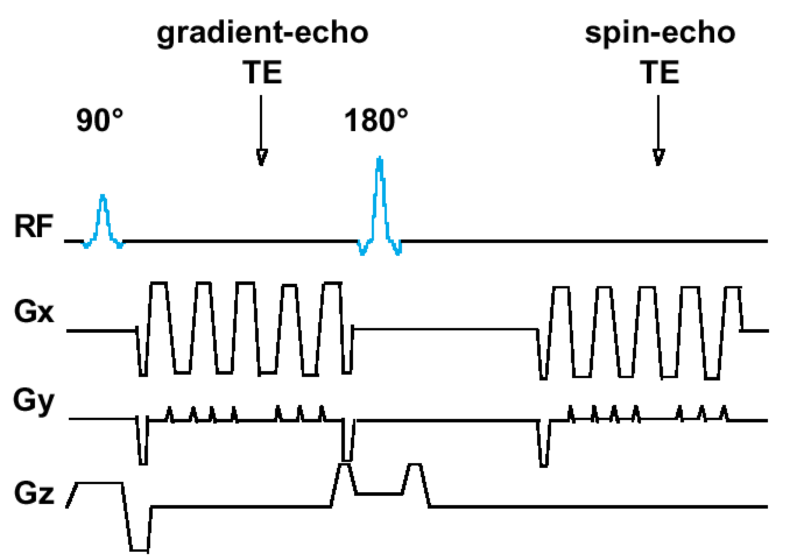
Assymetric Spin-echo

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.



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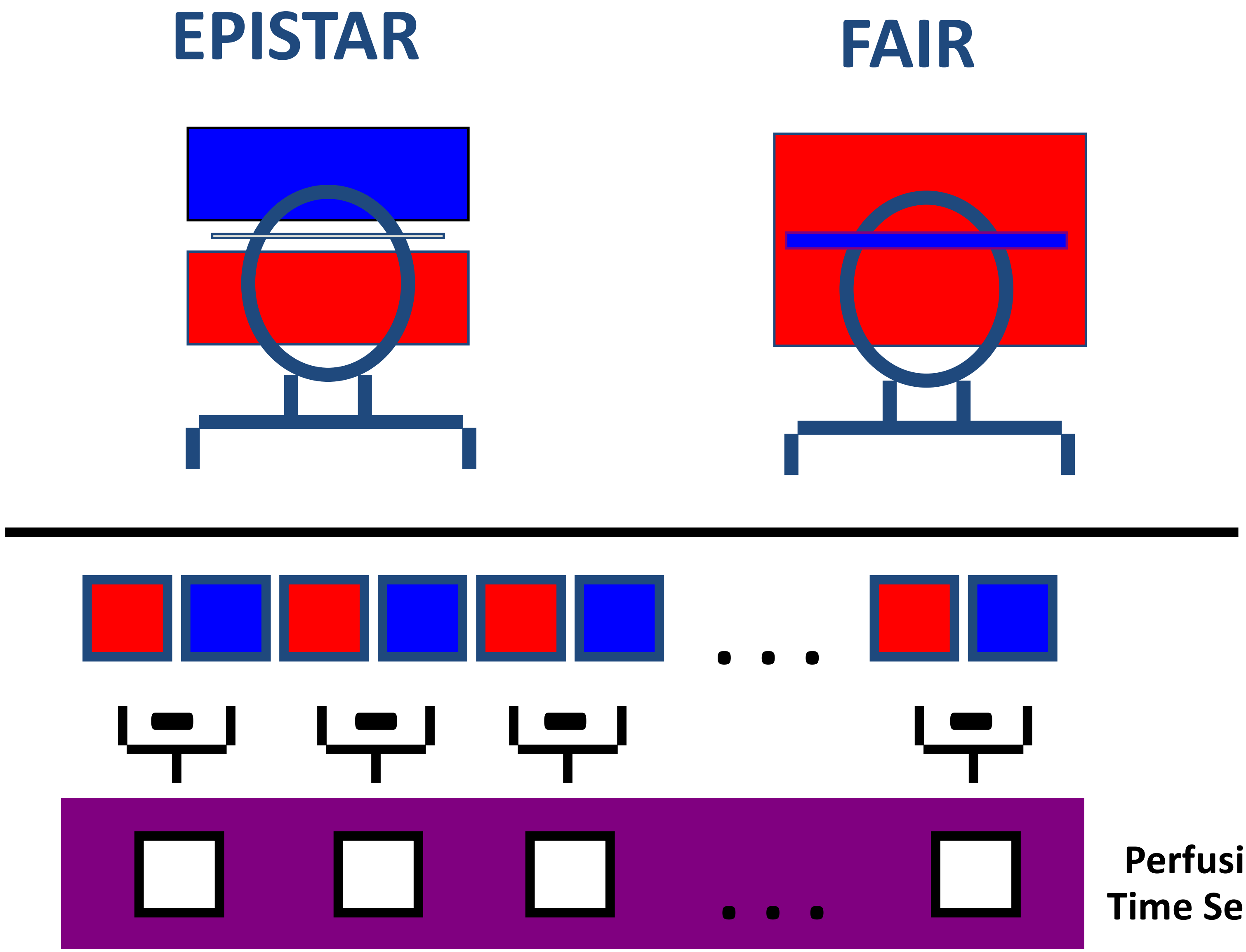
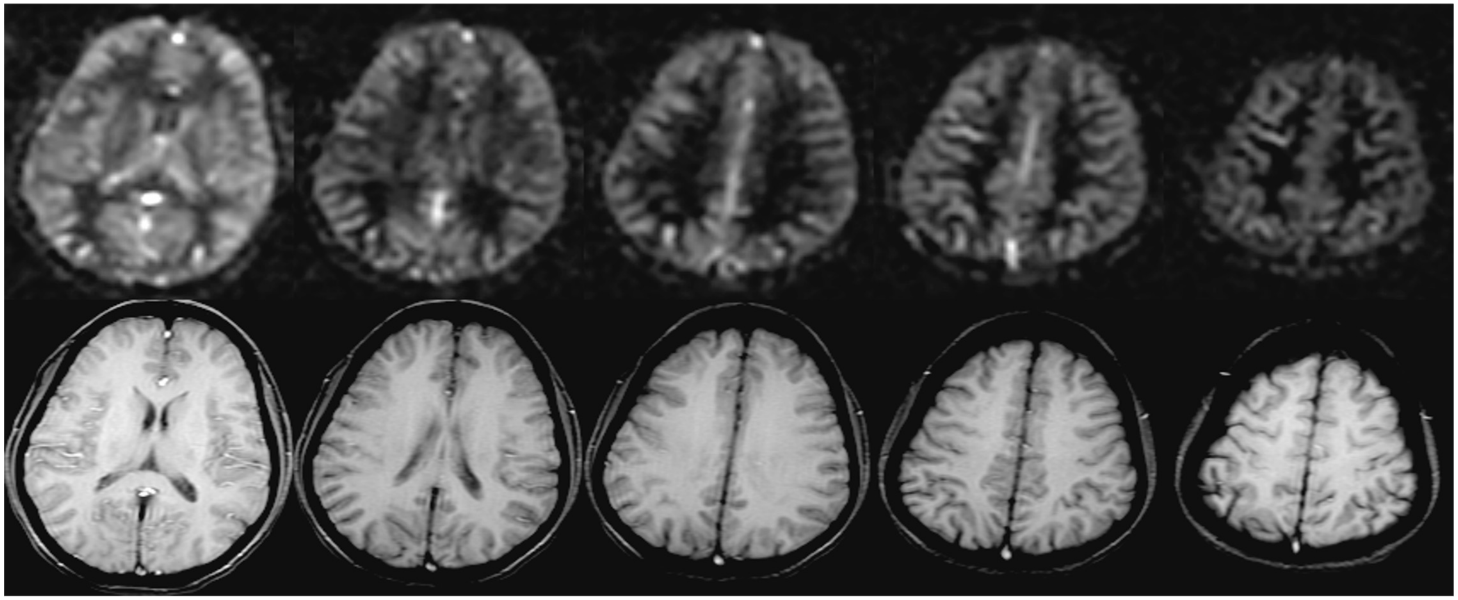
Arterial Spin Labeling

ASL



Perfusion Time Series

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.**

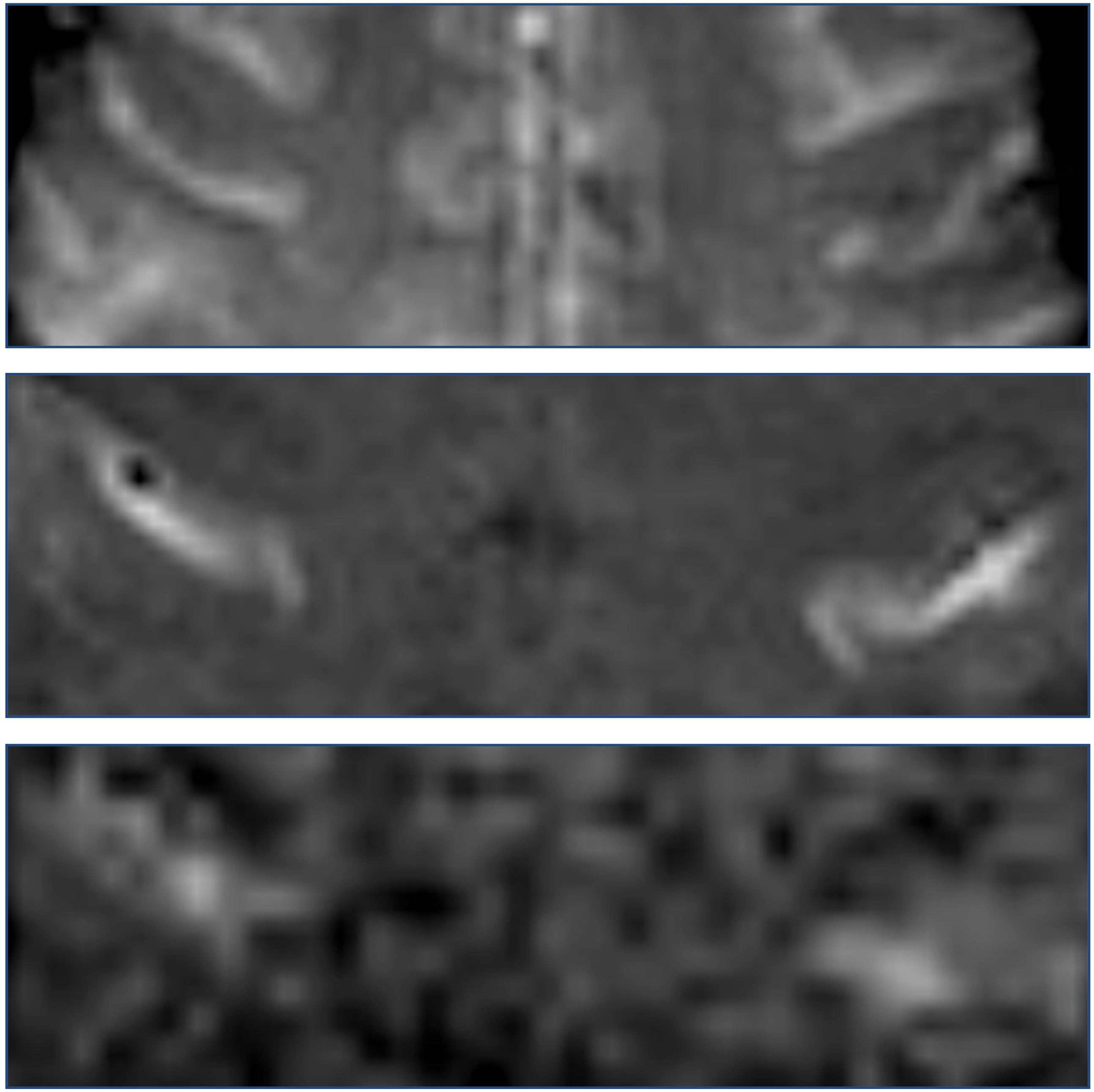
Kim, S.-G. (1995) "Quantification of relative cerebral blood flow change by flow-sensitive alternating inversion recovery (FAIR) technique: application to functional mapping." **Magn. Reson. Med. 34, 293-301**.

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

Anatomy

BOLD

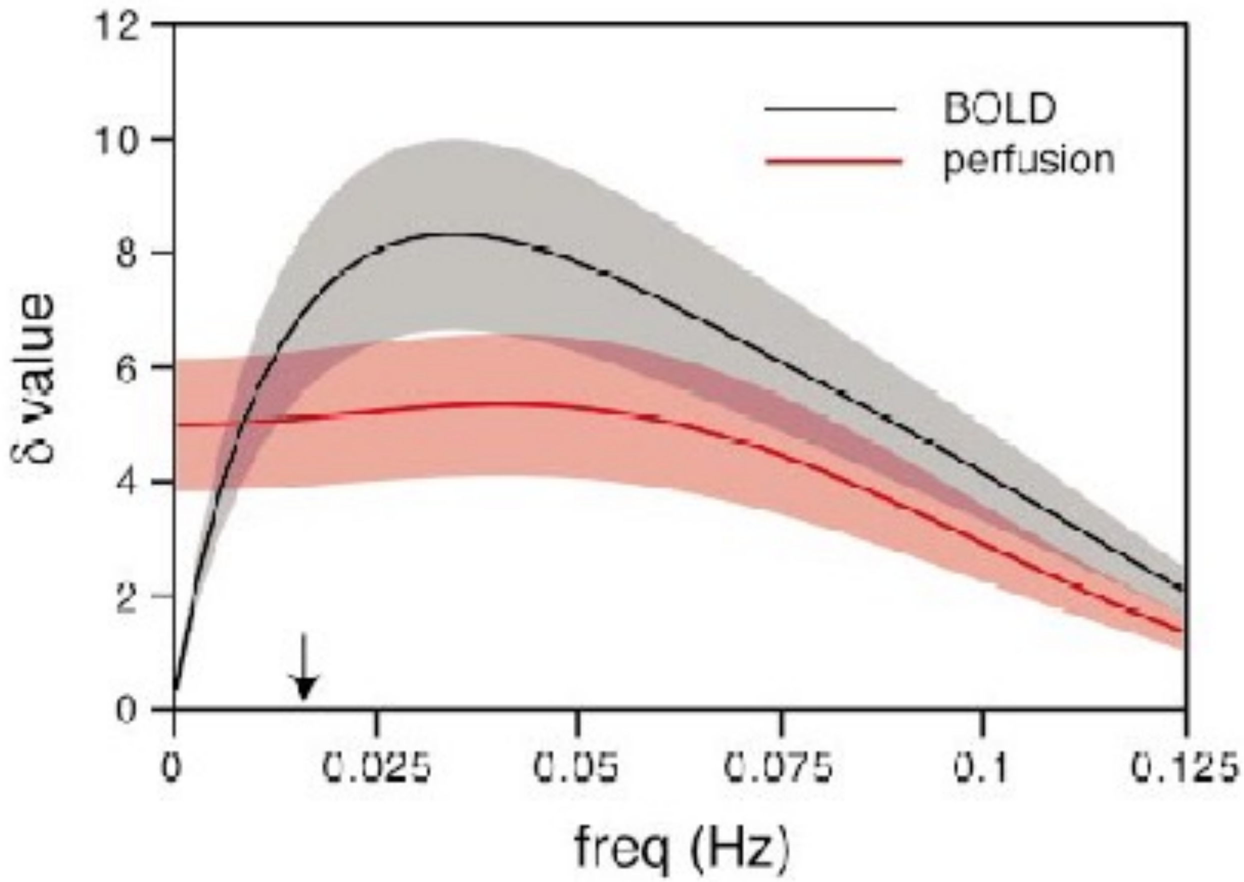
Perfusion



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.

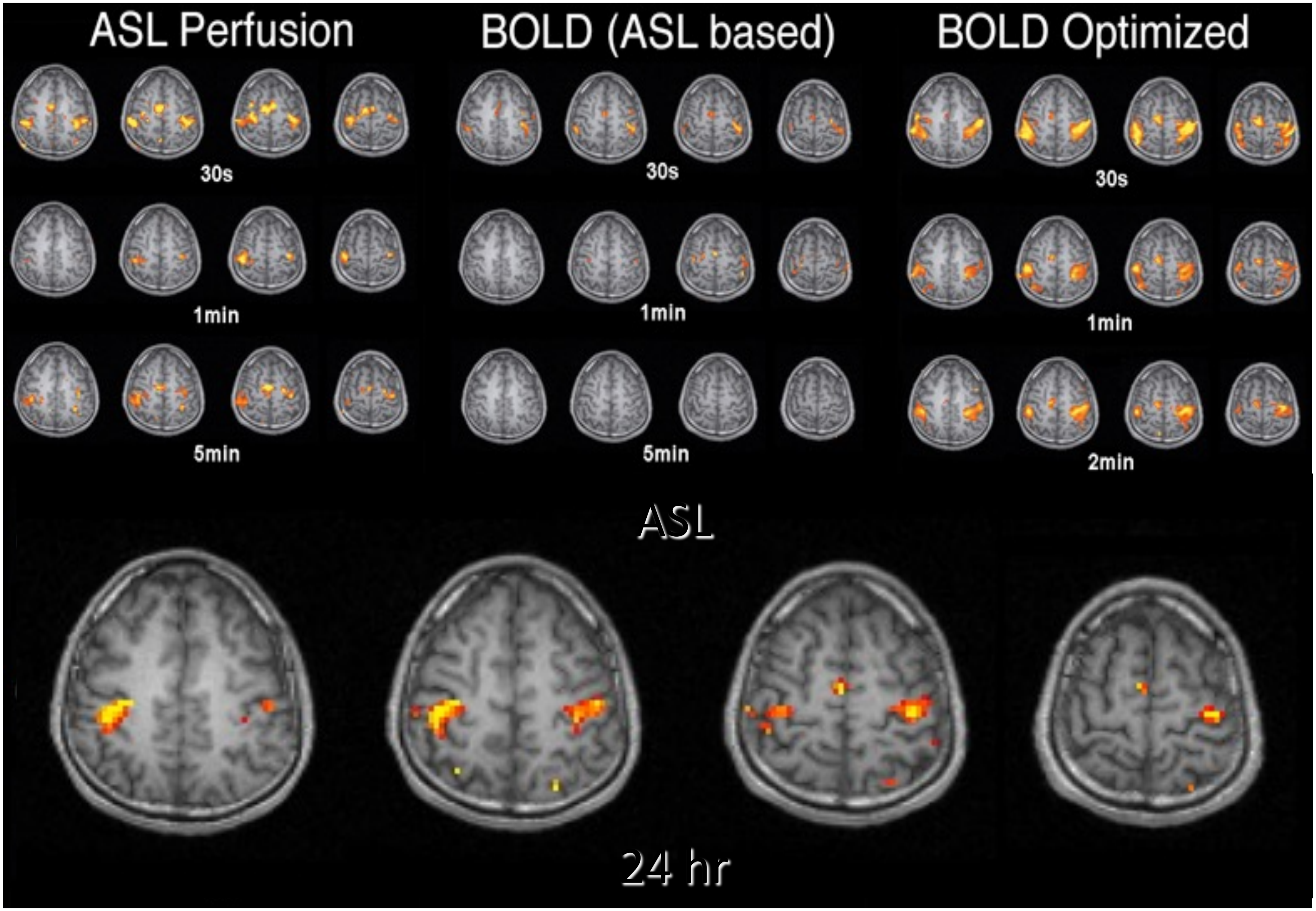
Arterial Spin Labeling

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

Acquisition:

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

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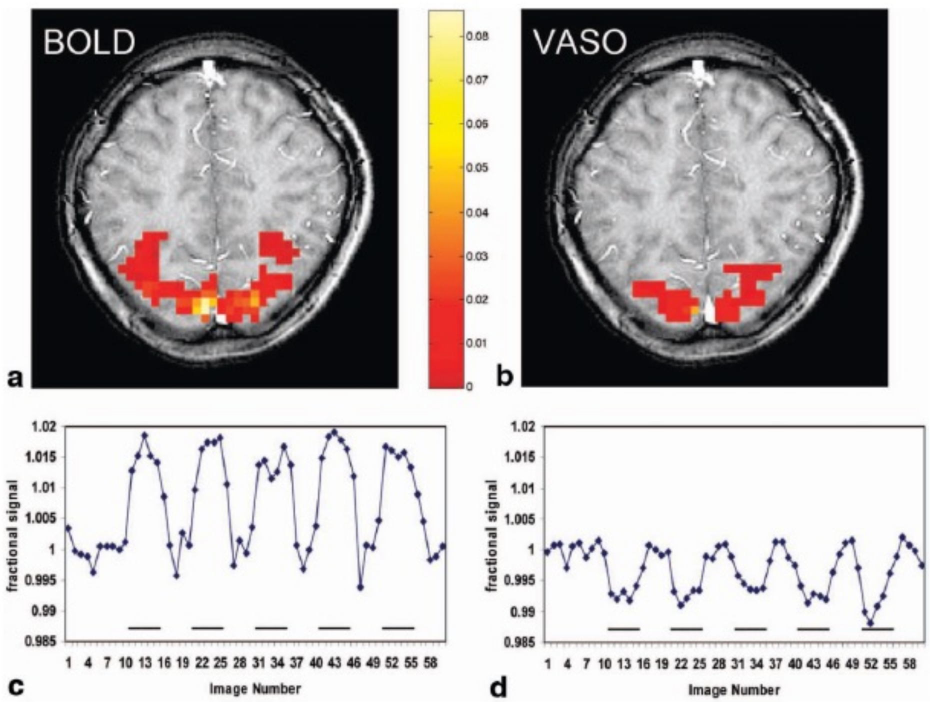
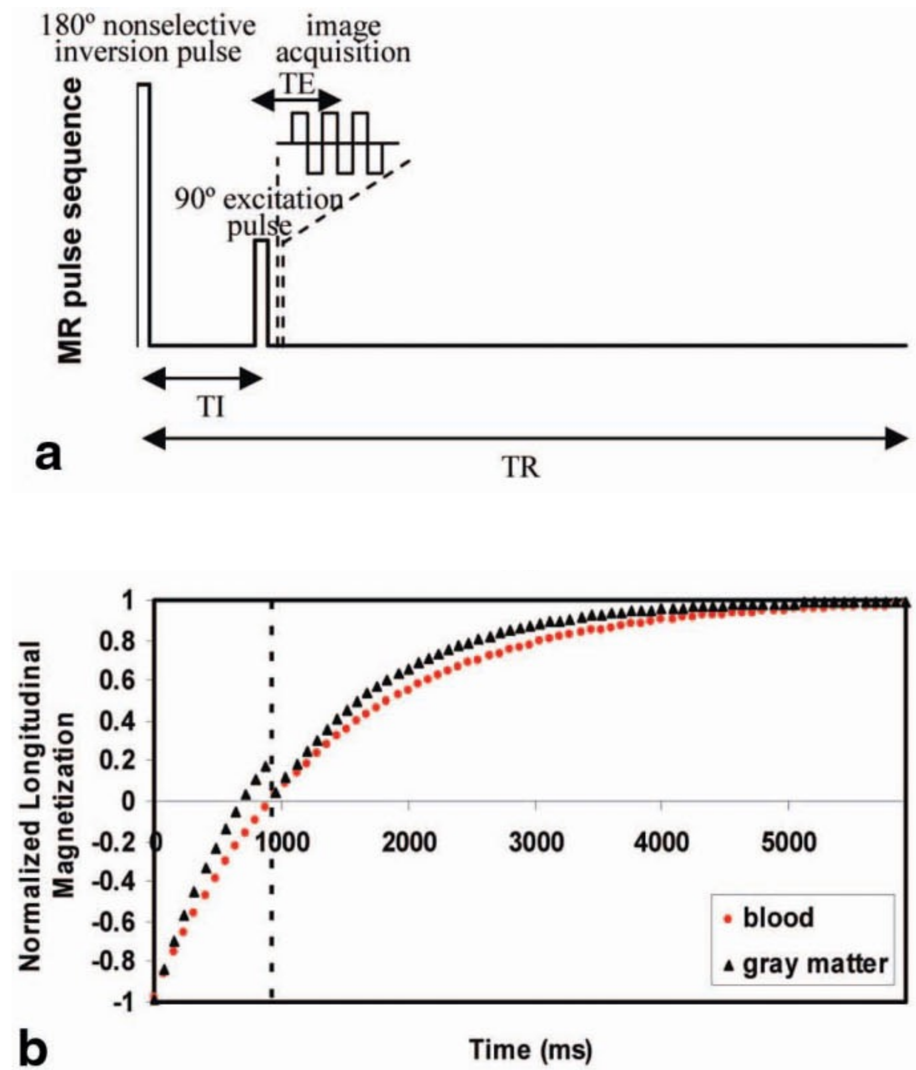
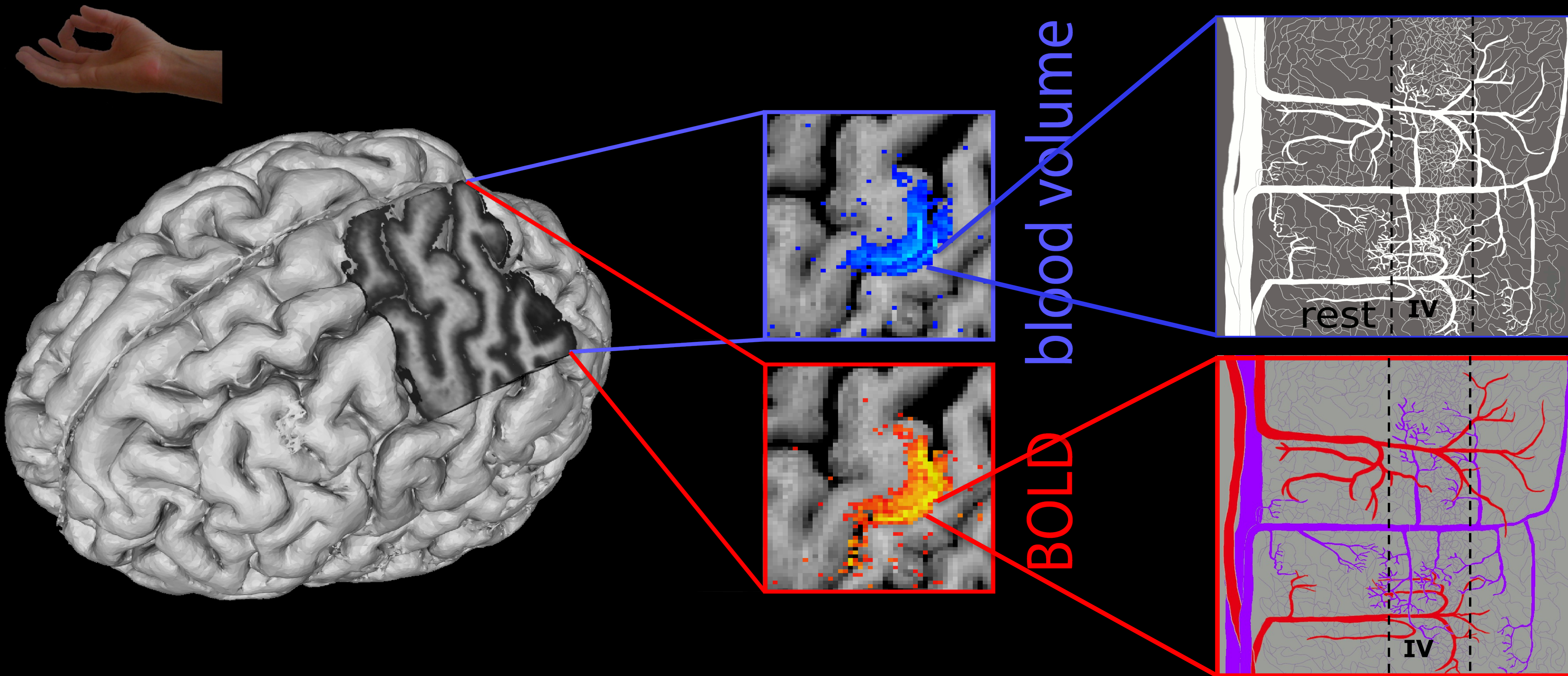
VASO





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

Local specificity of fMRI



[Huber et al., NeuroImage 2015]

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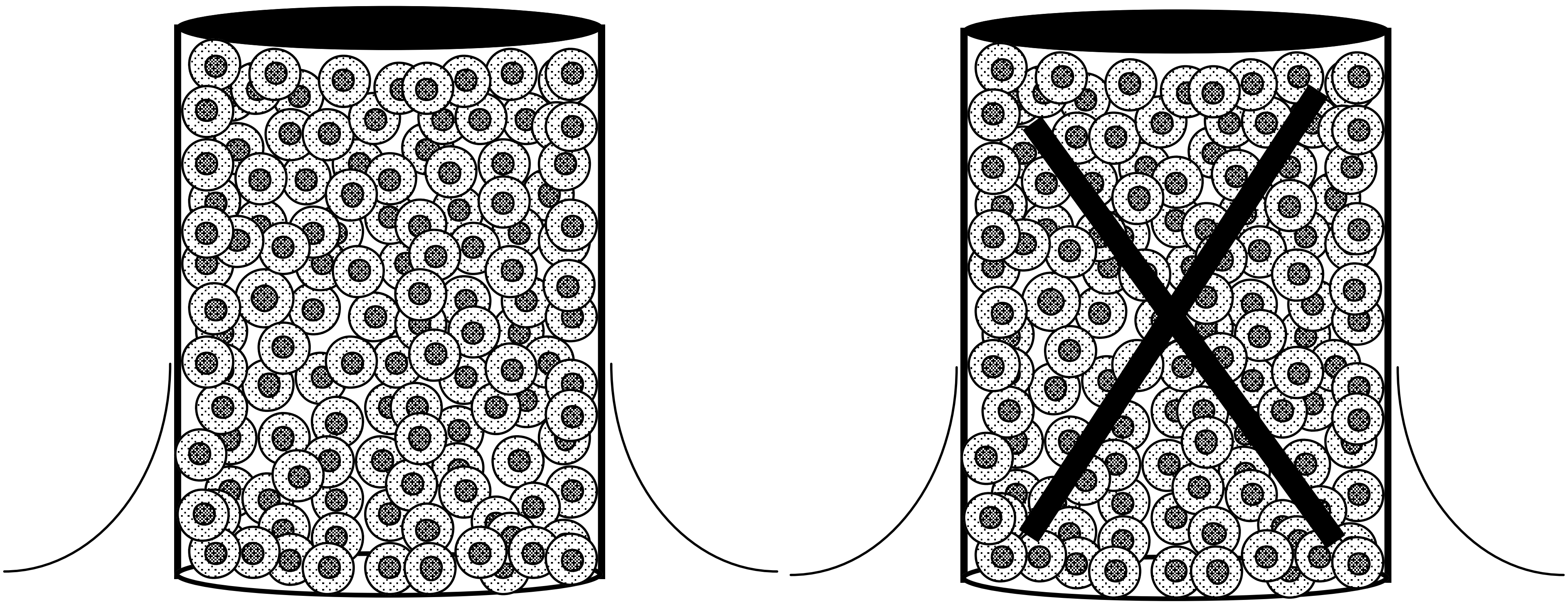
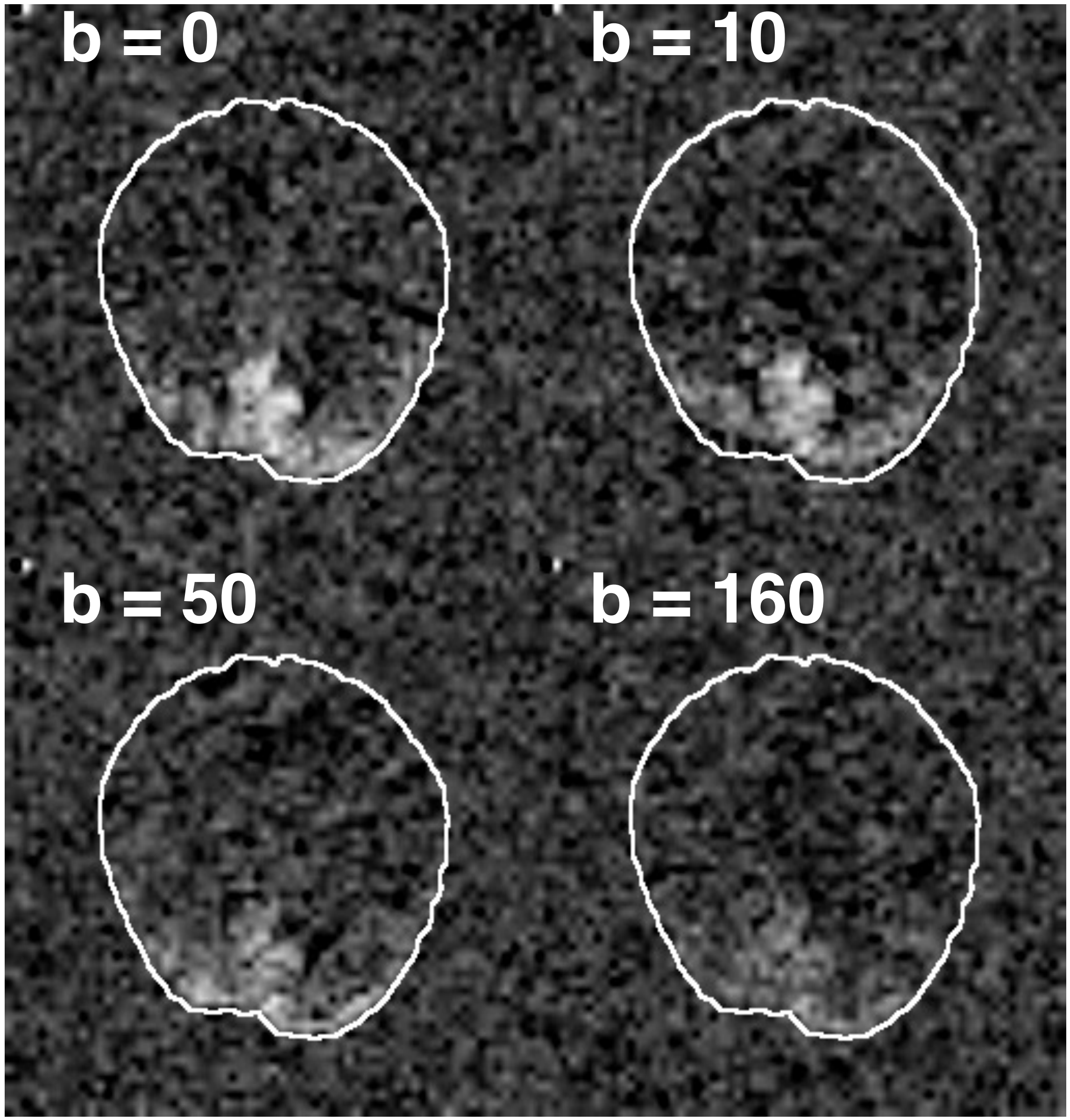
Low b Diffusion Weighting

no diffusion weighting **diffusion weighting**

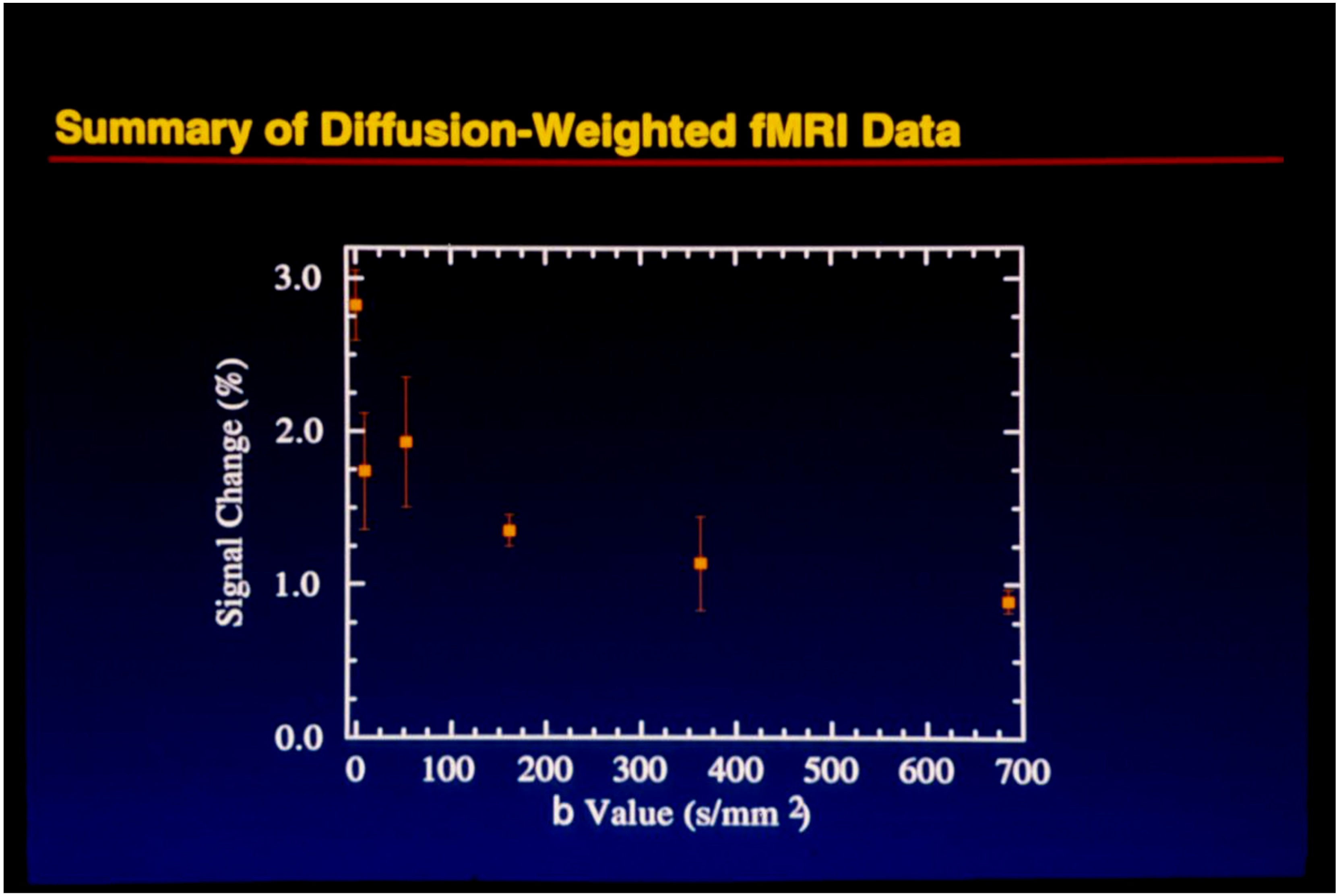


J. L. Boxerman, et al. MRM, 34, 4-10, (1995)
A. W. Song, et al. MRM, 35, 155-158 (1996)

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.
- Diffusion weighting and Spin-echo leaves one with no functional signal

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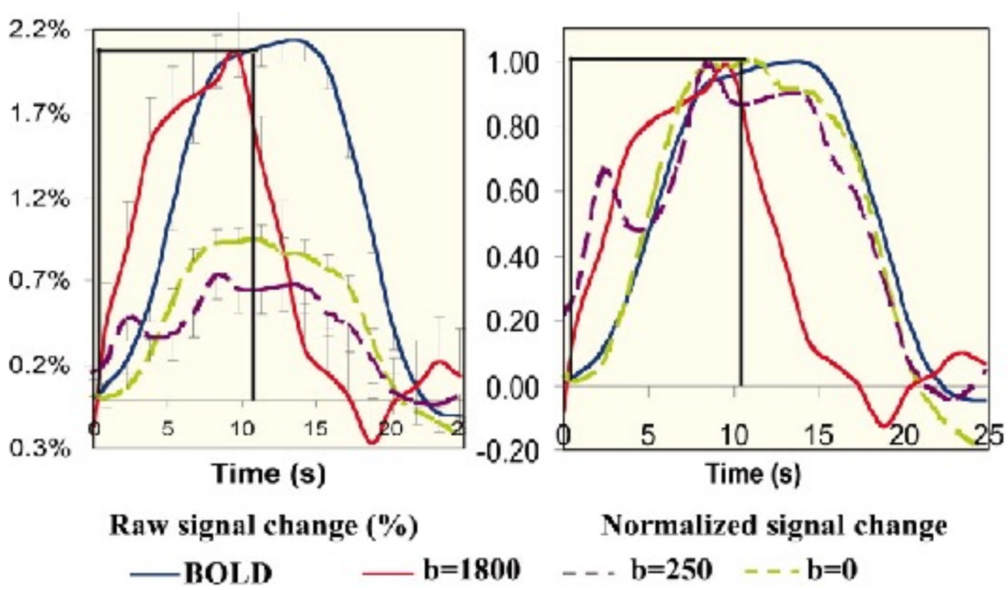
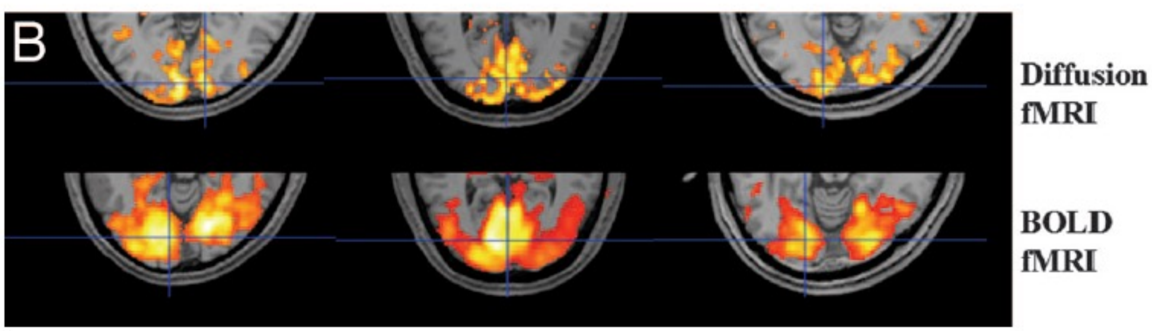
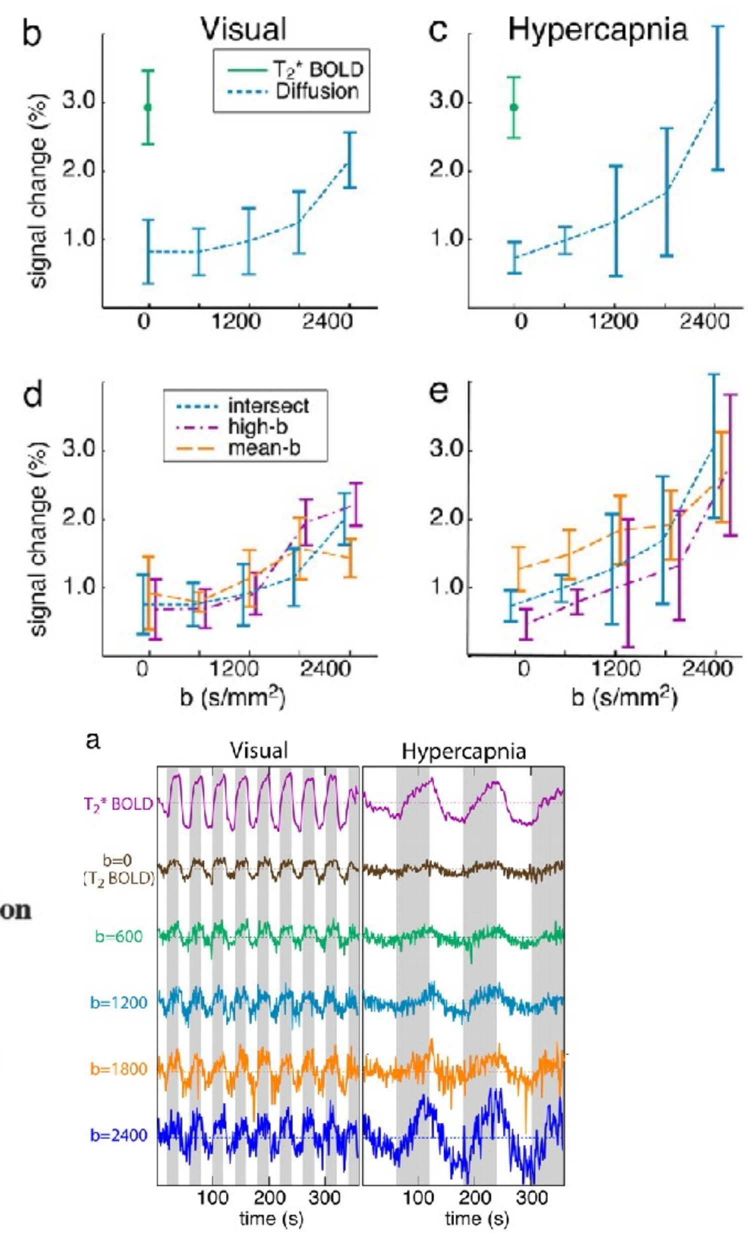
High b Diffusion Weighting







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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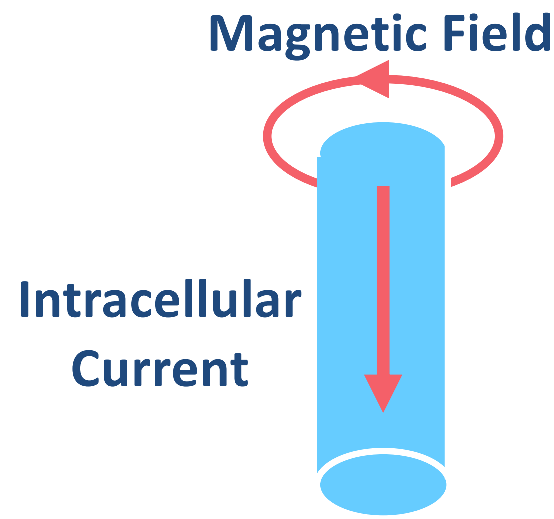
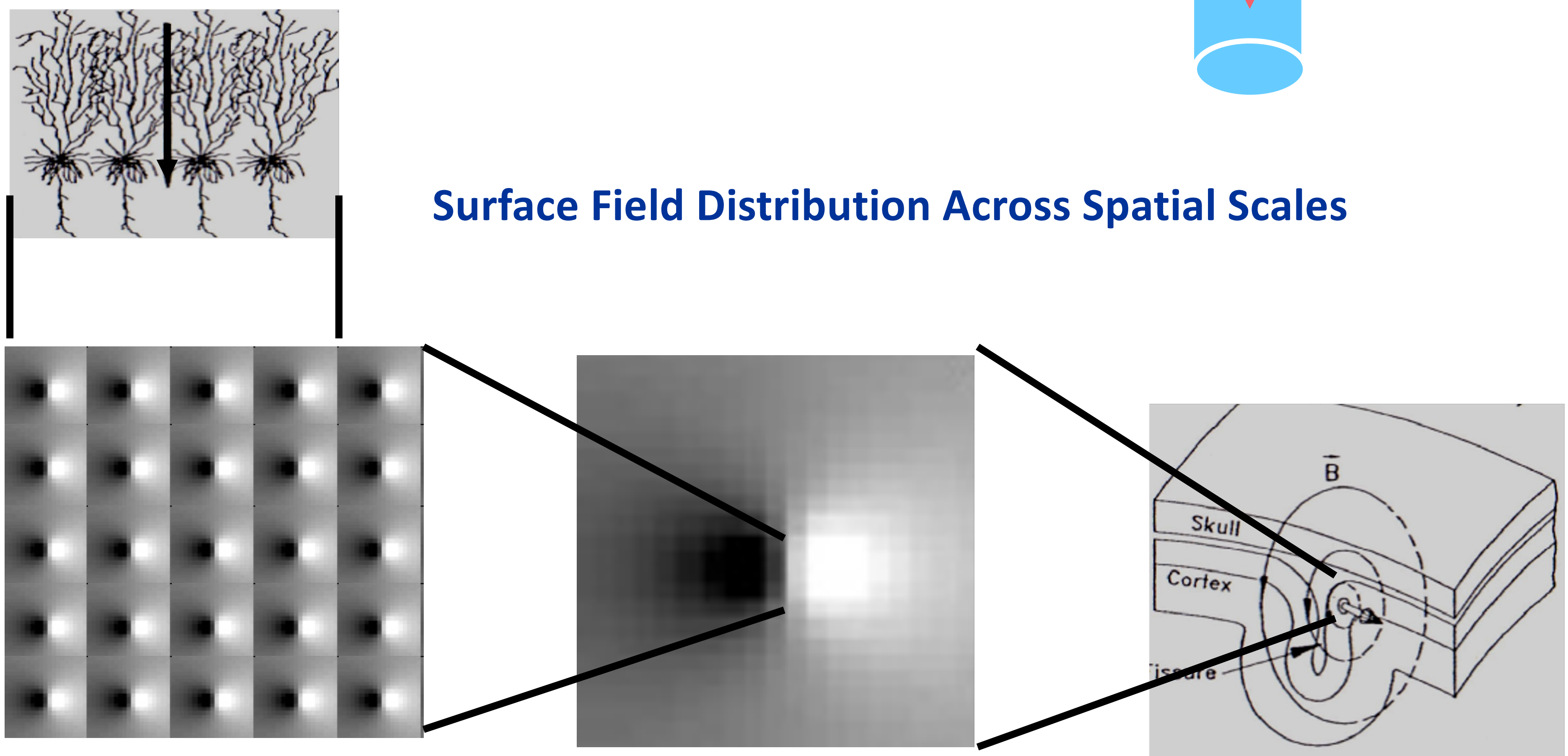
Neuronal Current Imaging



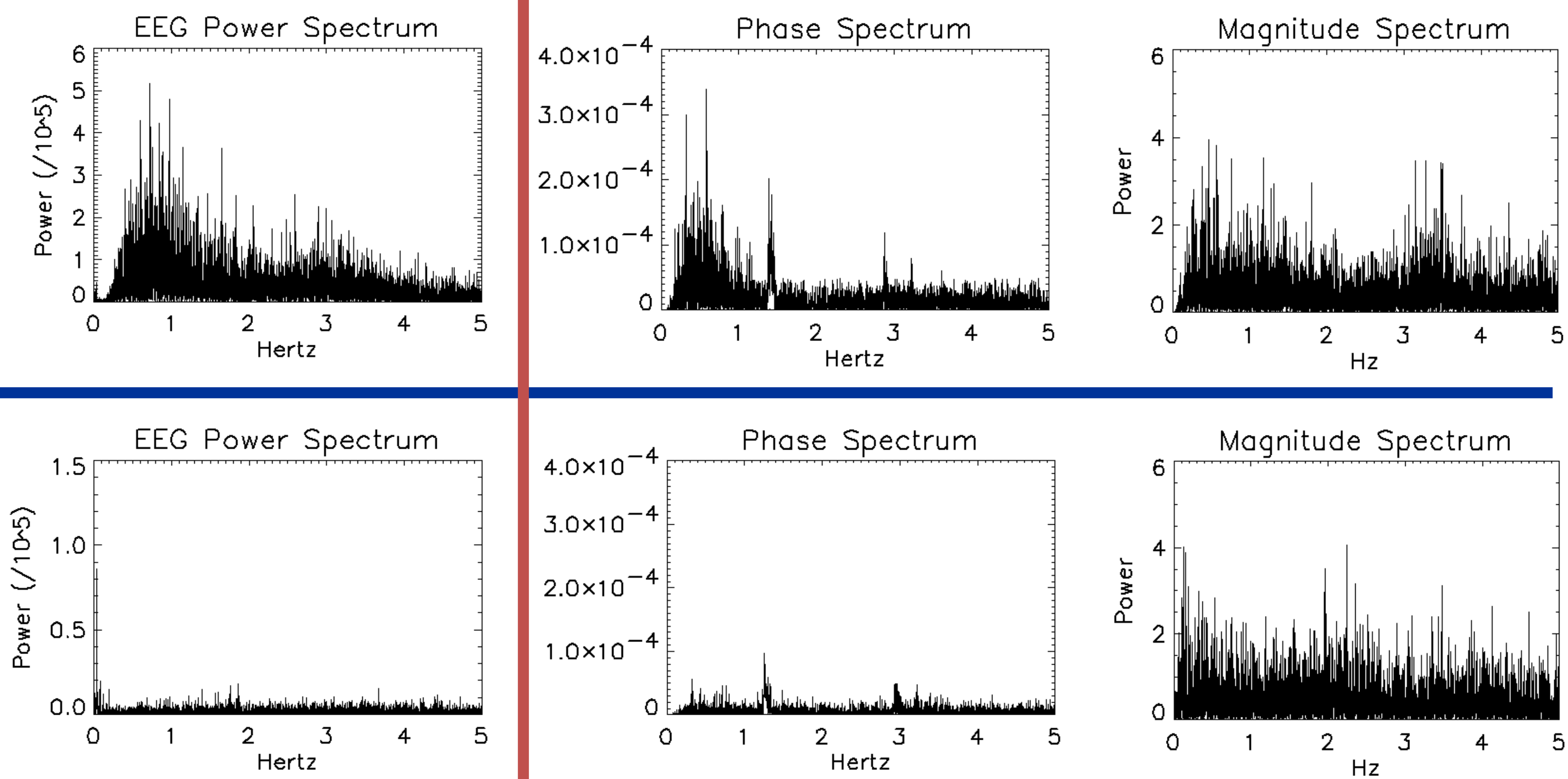


Adapted from: J.P. Wikswo Jr et al. *J Clin Neurophy* 8(2): 170-188, 1991

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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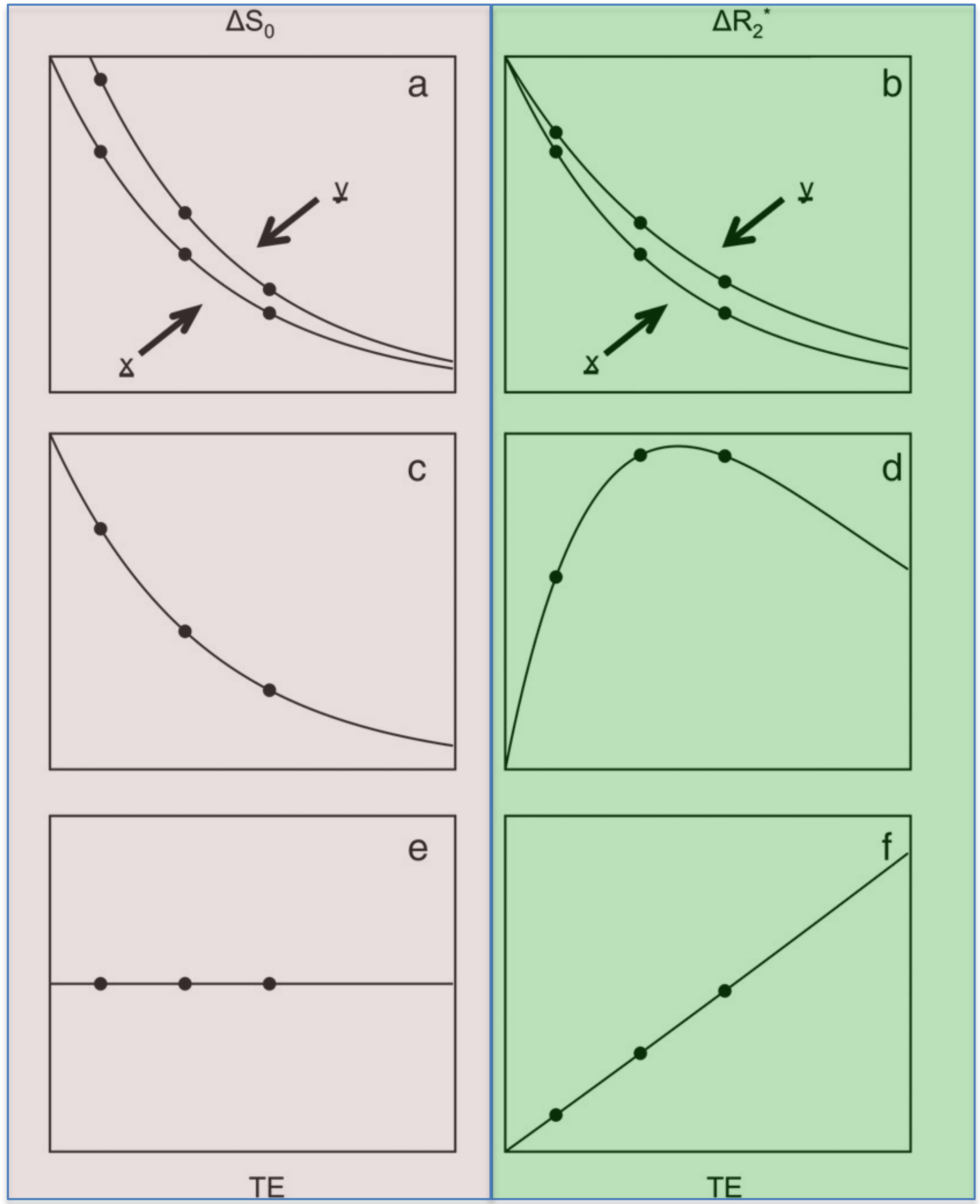
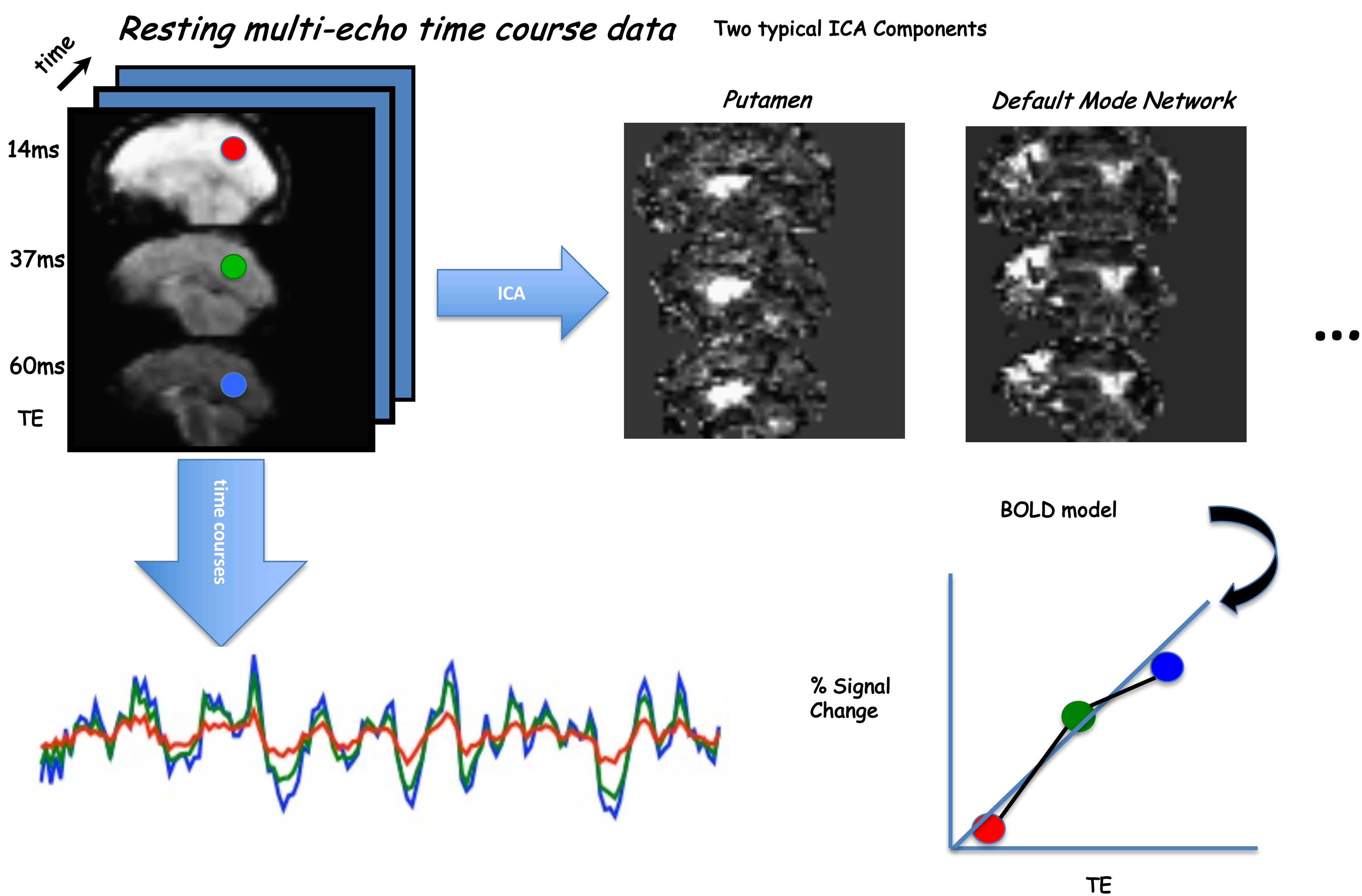
Non-BOLD BOLD

Rest and activation

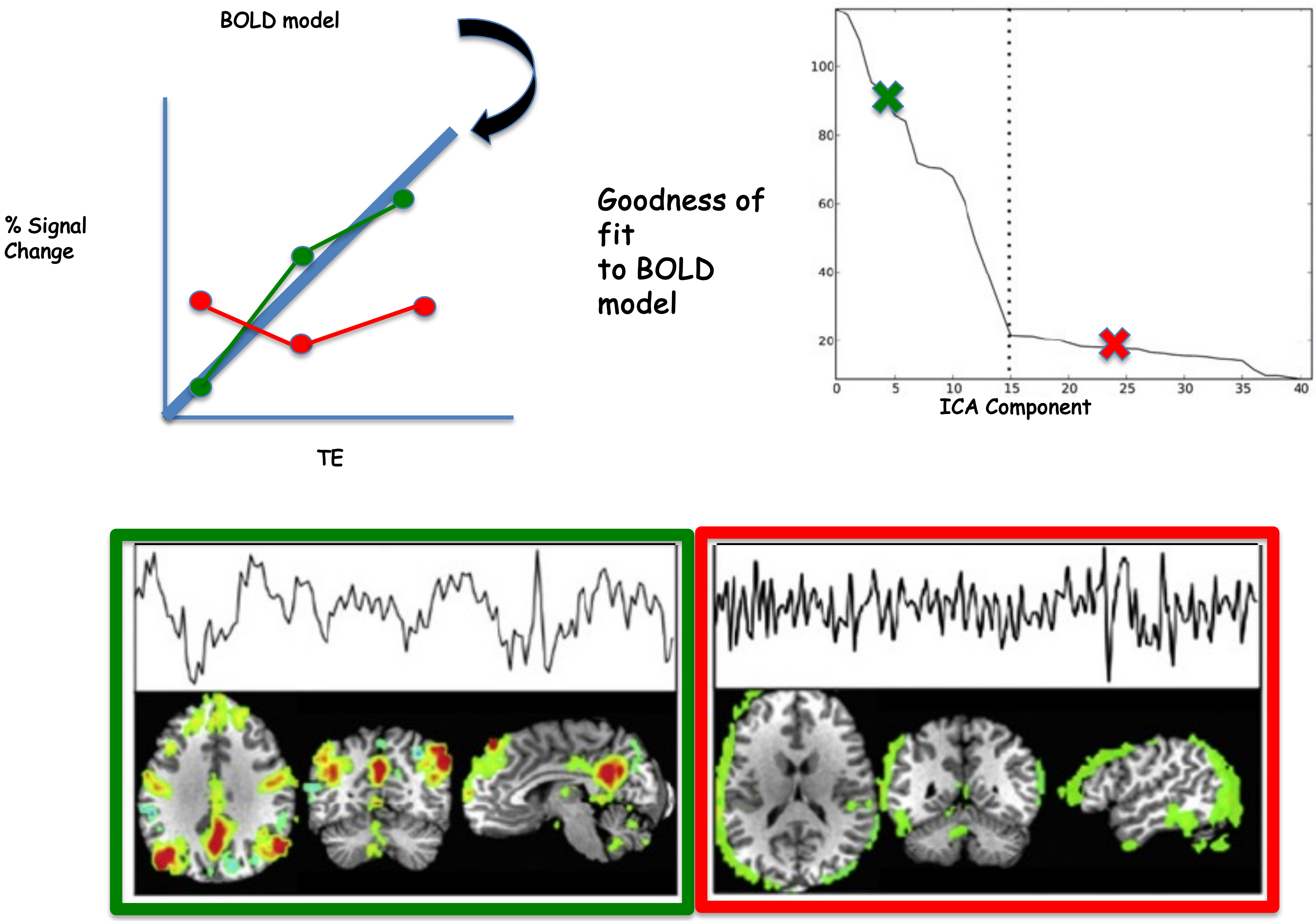
Difference

Percent change

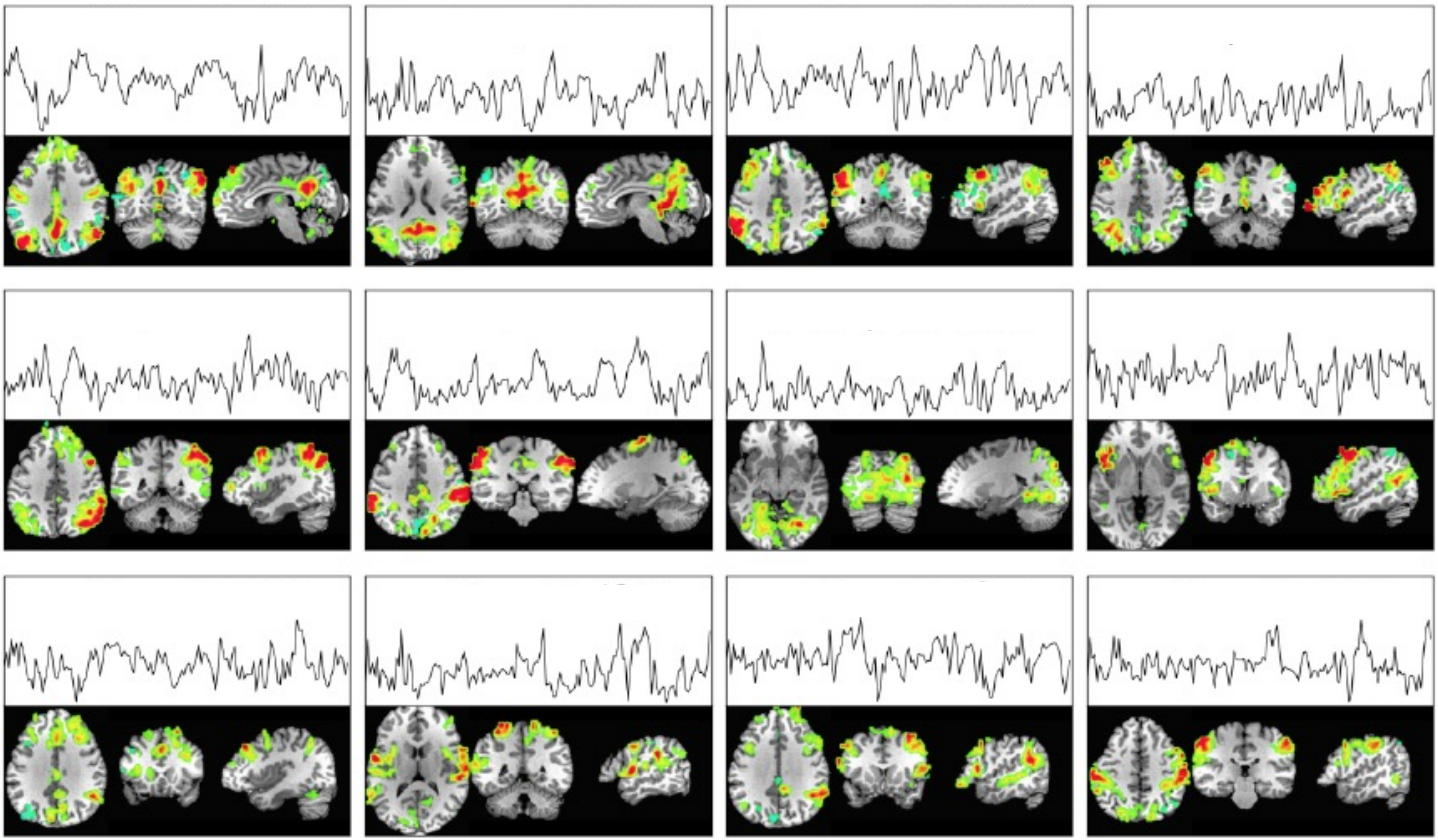




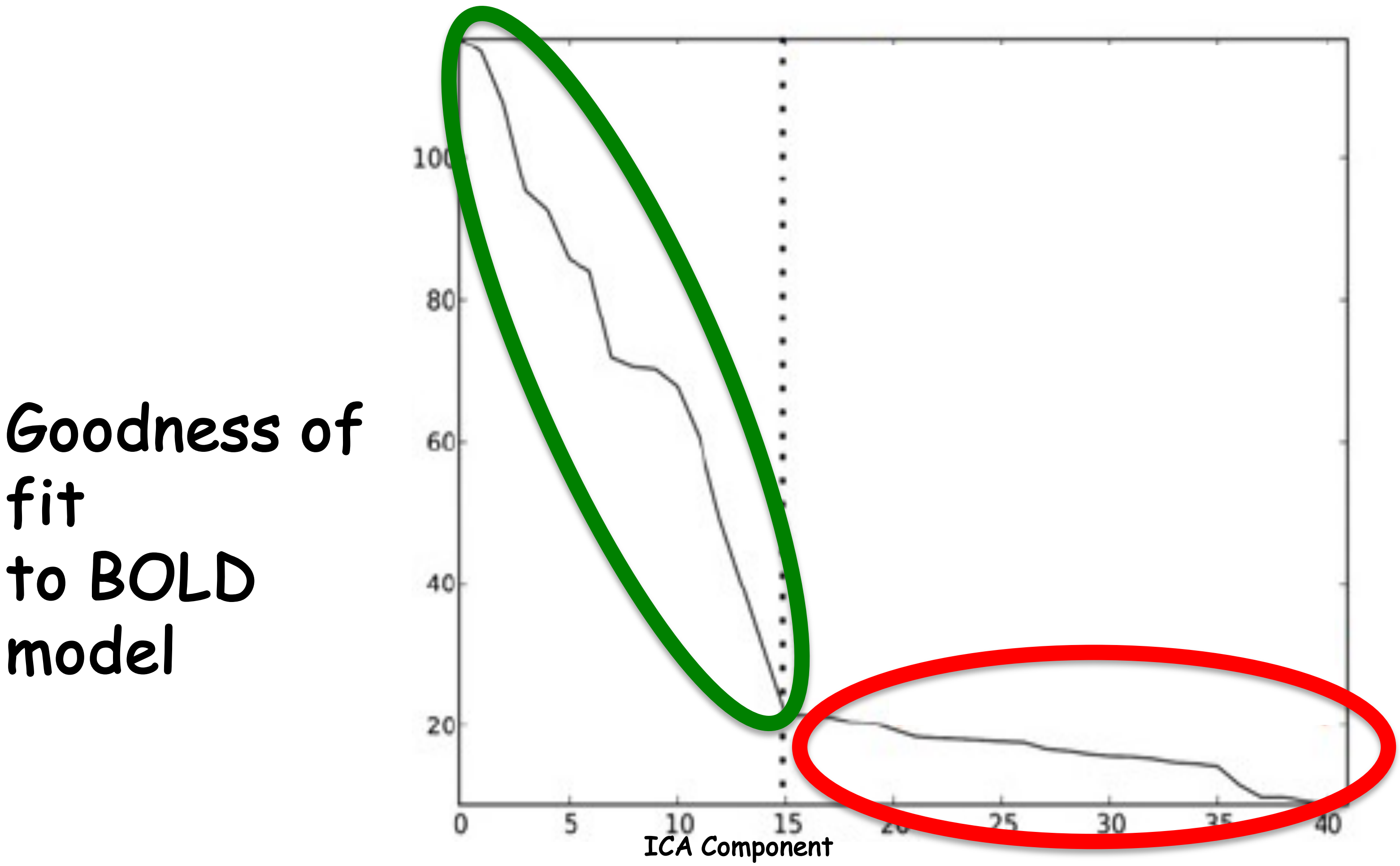
Resting multi-echo time course data
Two typical ICA Components
time
14ms
37ms
60ms
TE
ICA
Putamen
Default Mode Network
...
time courses
BOLD model
% Signal Change
TE


BOLD model
% Signal Change
TE
Goodness of fit to BOLD model
100
80
60
40
20
0
5
10
15
20
25
30
35
40
ICA Component

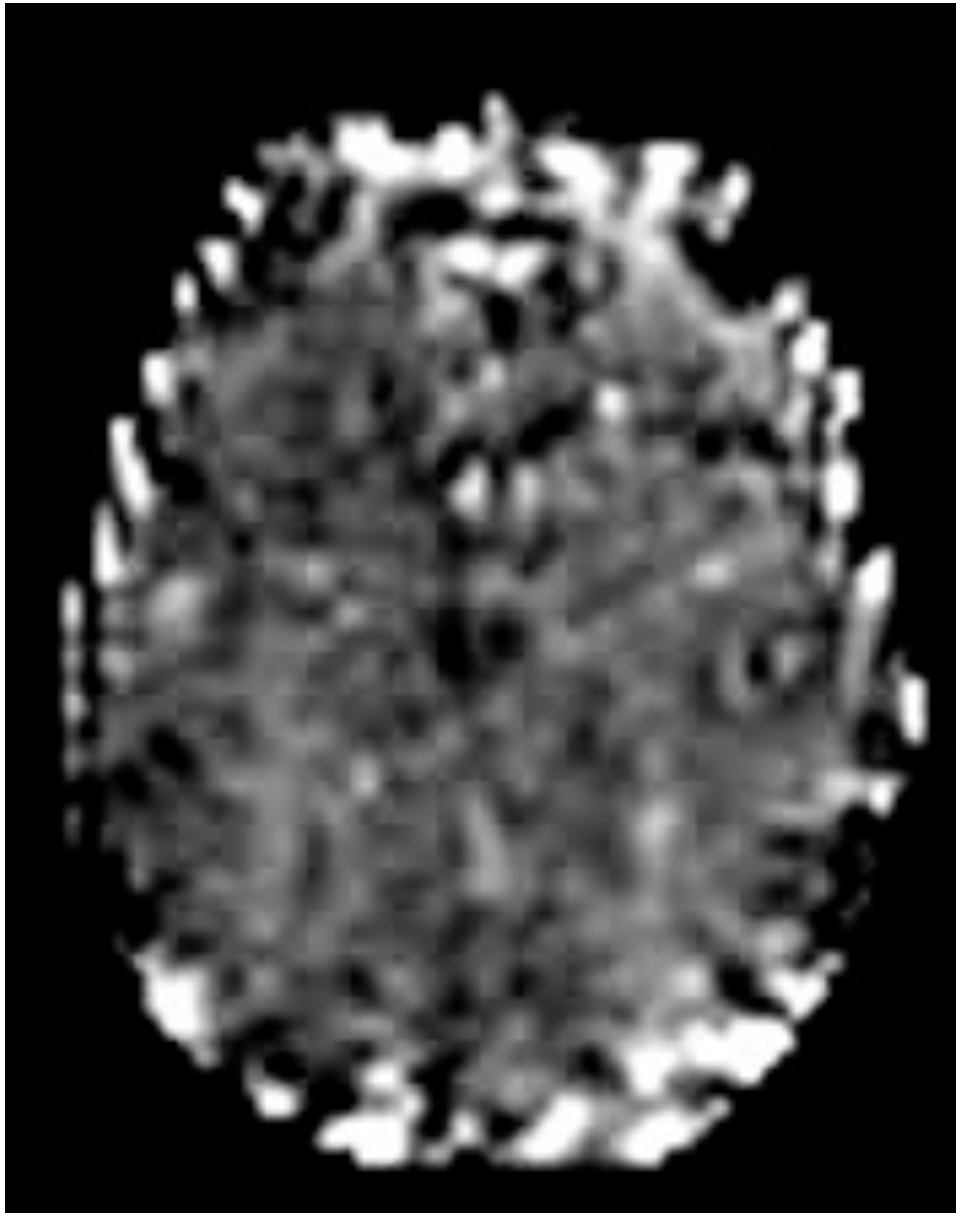
Automatic Selection of BOLD Component Maps



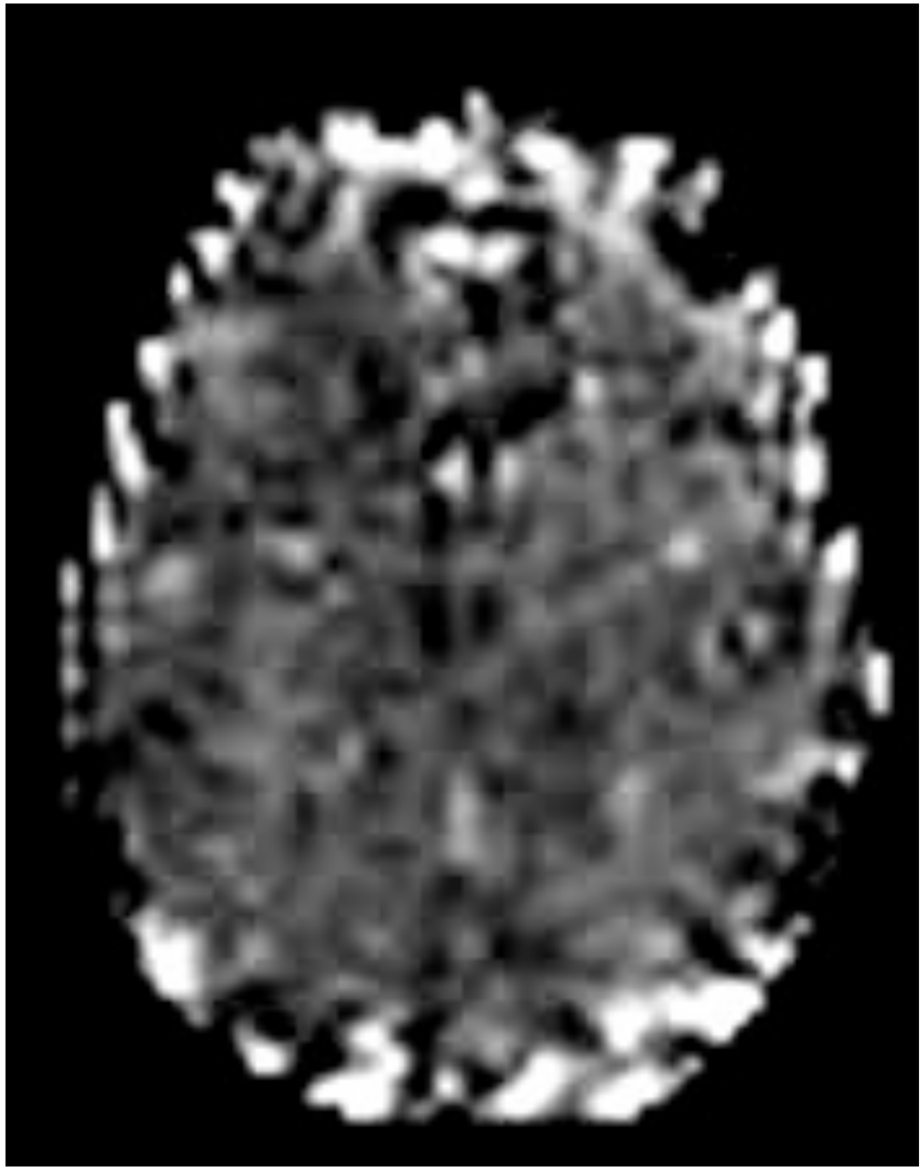
Clustering is extremely robust on small groups and on individuals when using multi-echo selected BOLD Components.



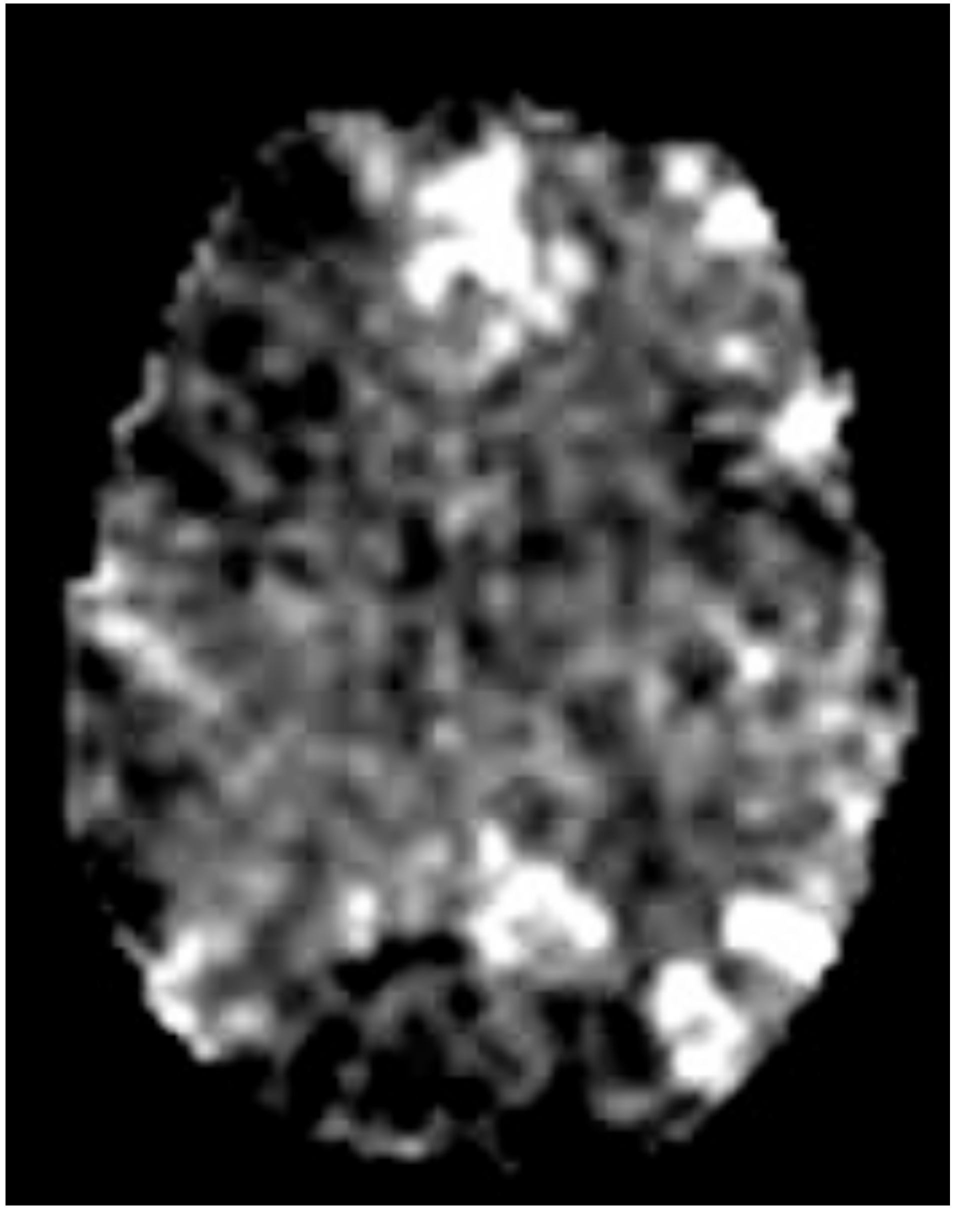
Typical raw time series signal



Non-BOLD fluctuations…what is regressed out.



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



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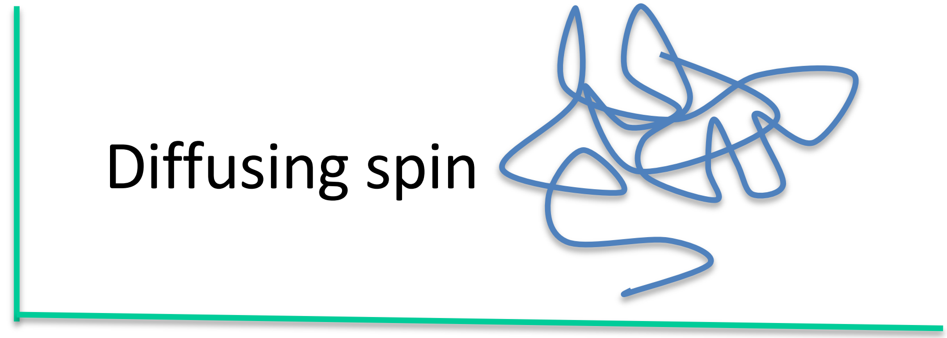
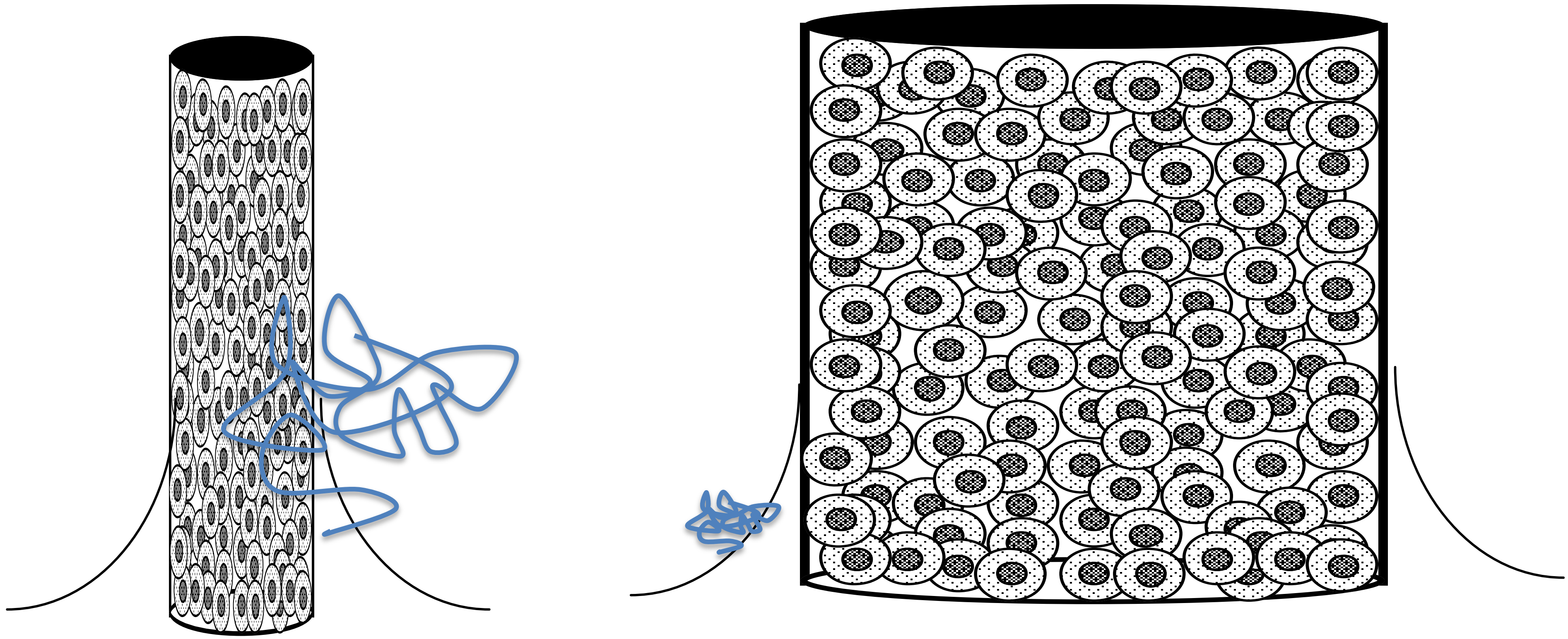




δphase = 0
δmagnitude = 1

δphase = 1
δmagnitude = 1

NeuroImage 49 (2010) 3149–3160

Contents lists available at ScienceDirect

NeuroImage

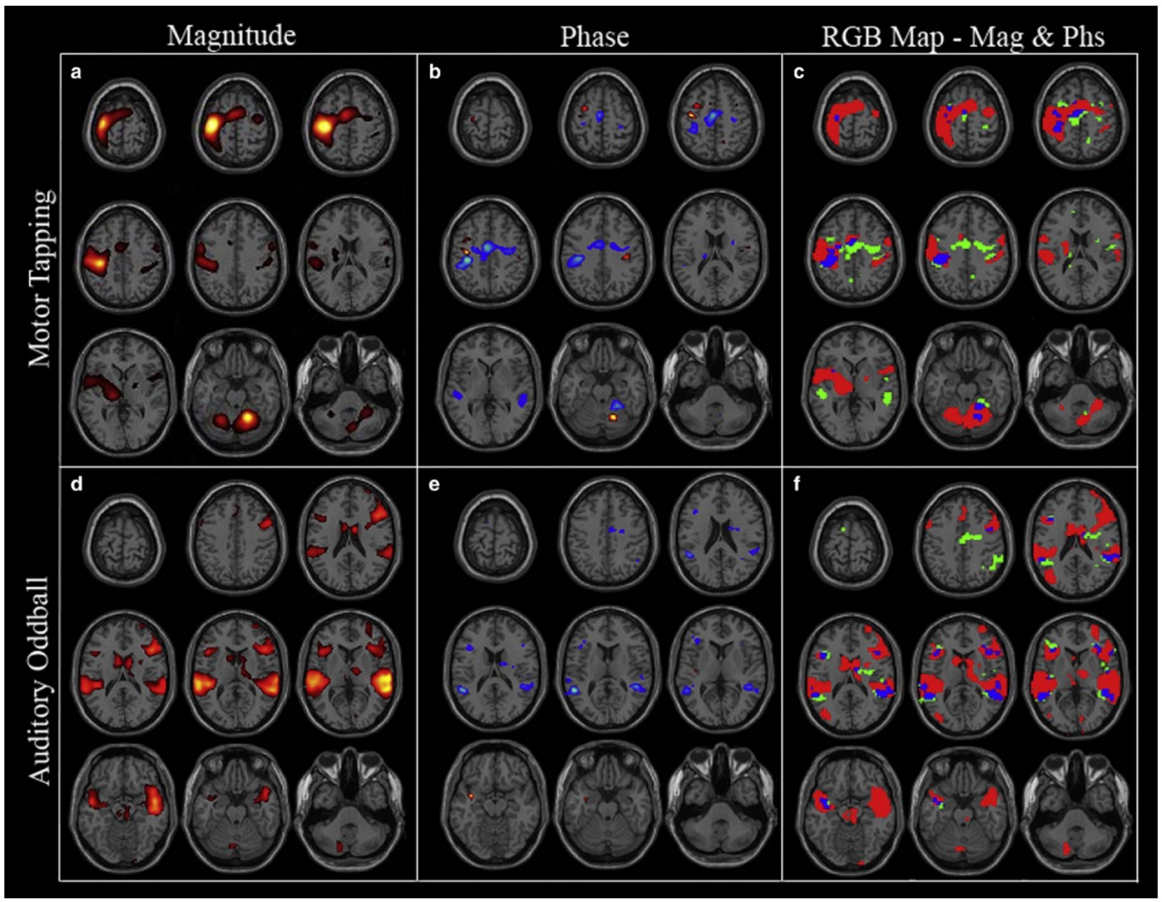
journal homepage: www.elsevier.com/locate/ynimg

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

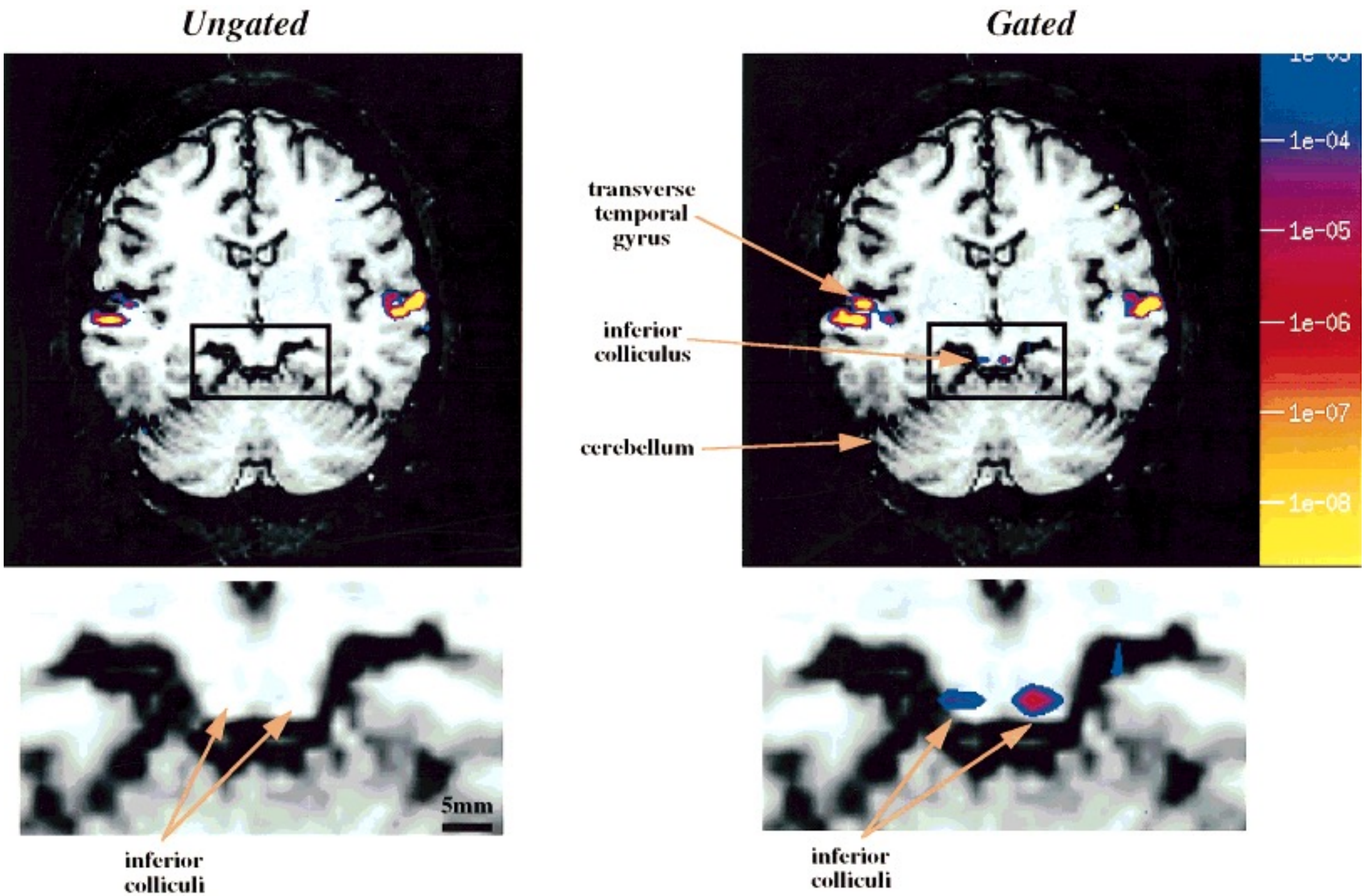
◆ Human Brain Mapping 6:33–41(1998) ◆

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

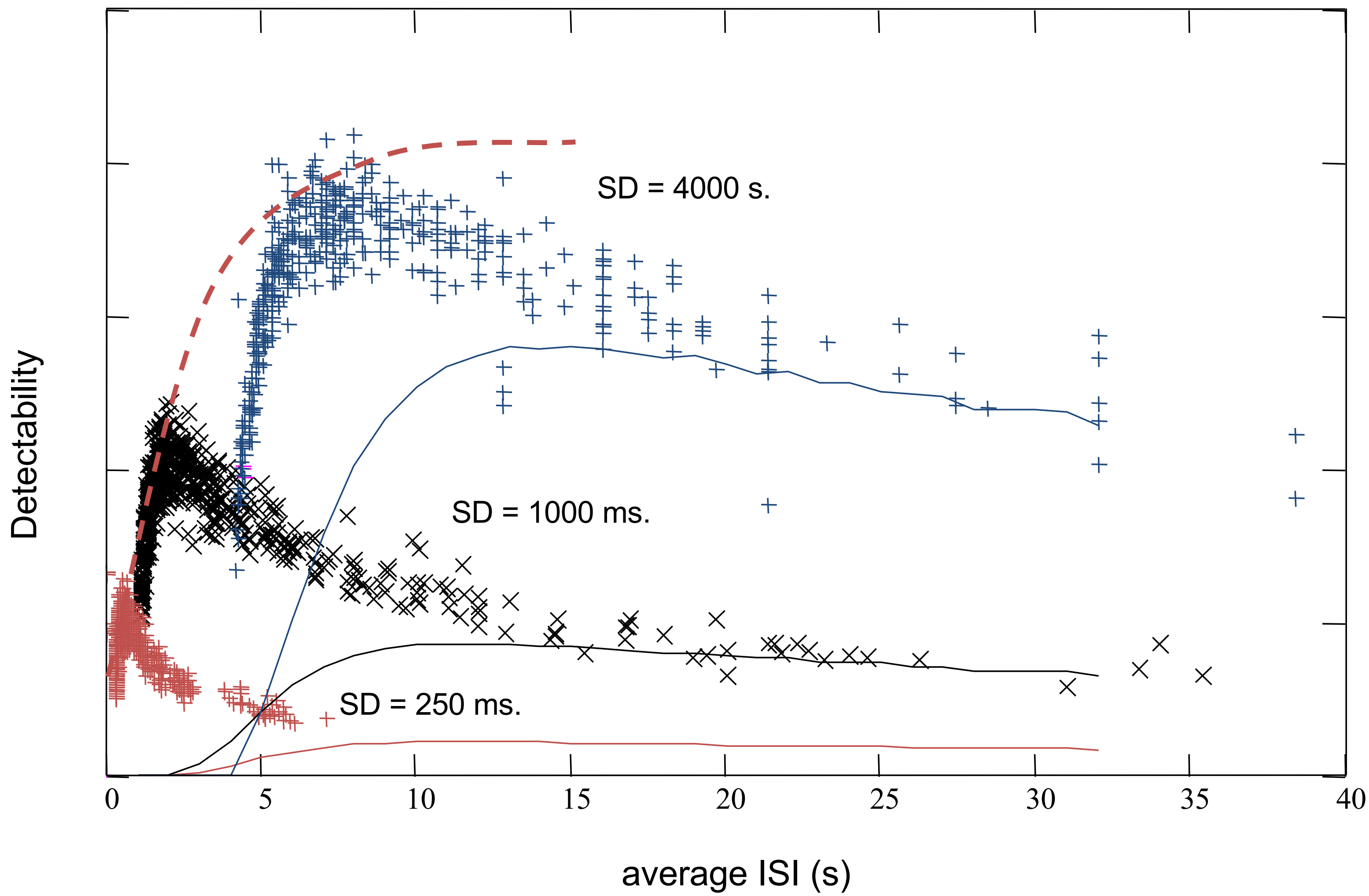
Detection versus Estimation in Event-Related fMRI: Choosing the Optimal Stimulus Timing

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*

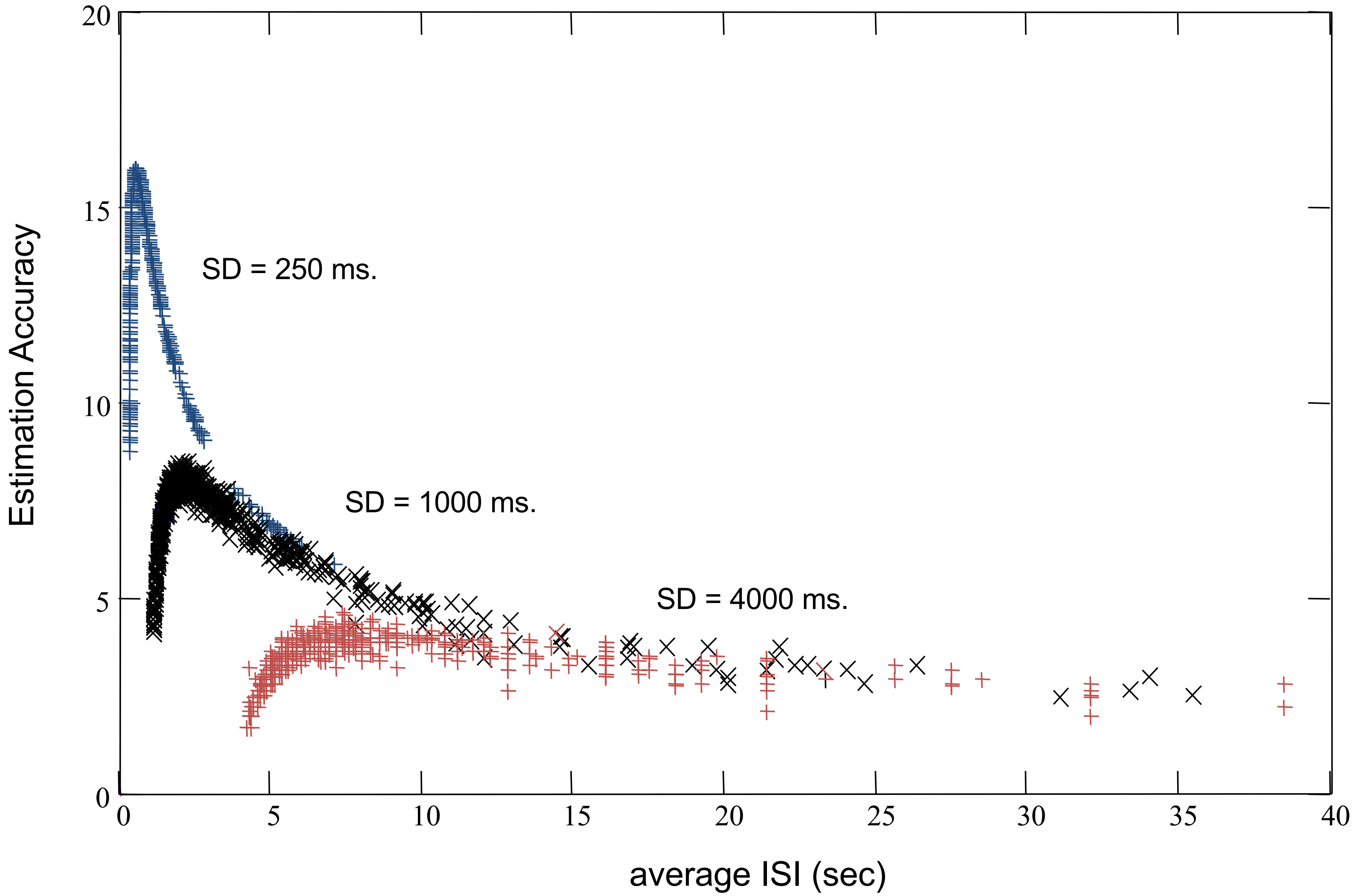
Received December 28, 2000

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



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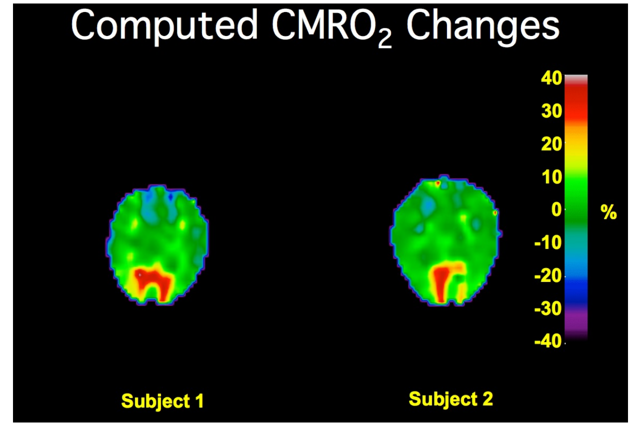
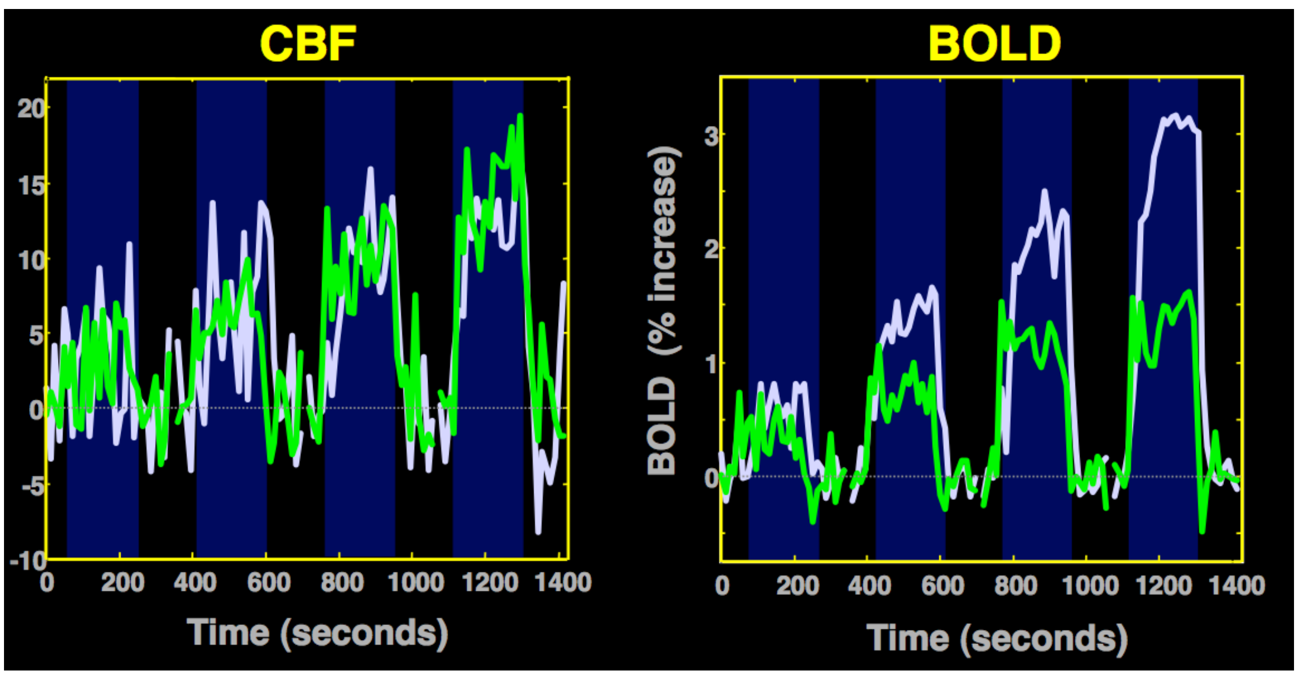
Calibration and Global Stressors



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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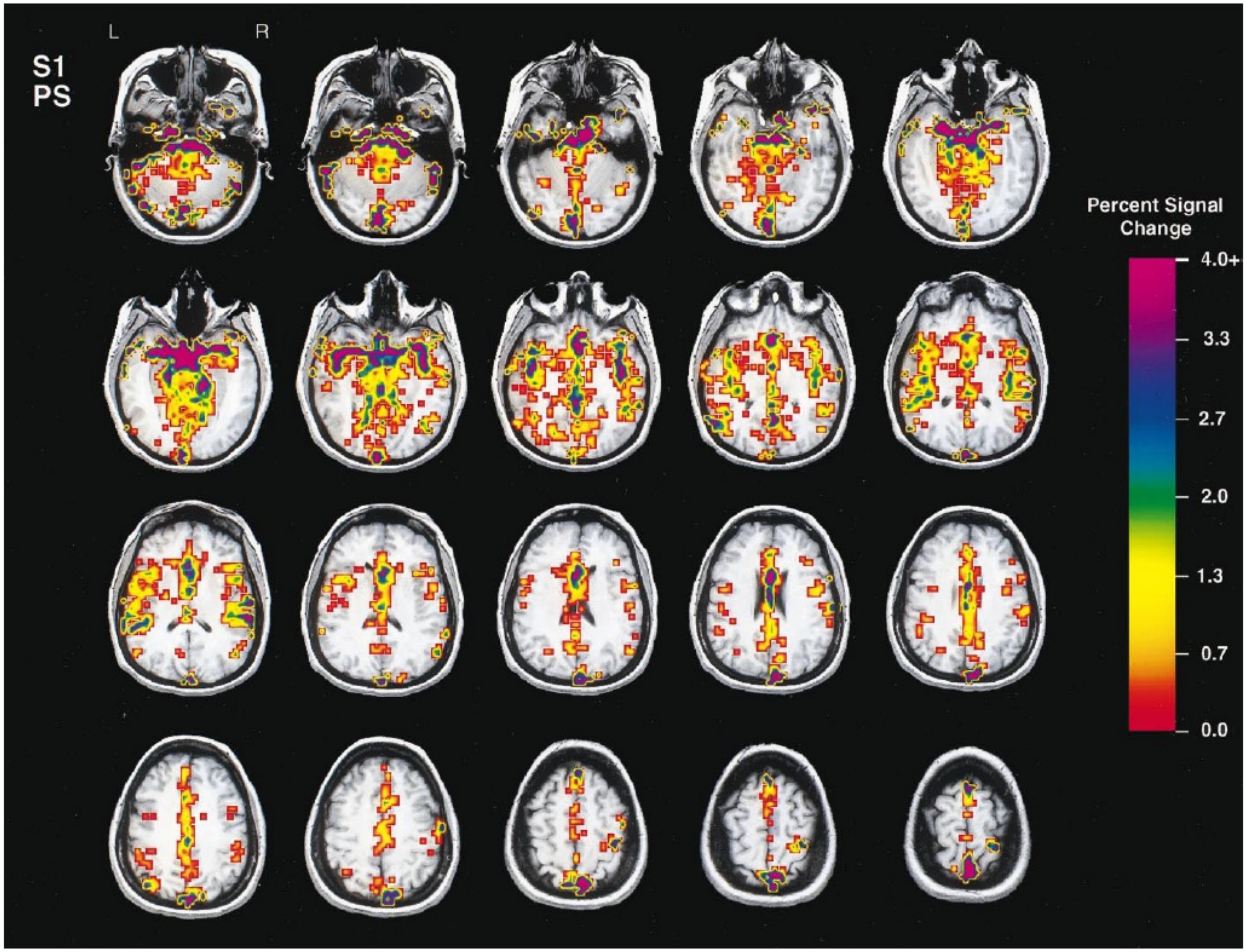
Data – based Cardiac Noise Removal



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

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
- calibration or global stressors
- vessel identification and masking (standard deviation, dark dots, latency…)
- noise regression from regions in brain (sagittal sinus, etc..)
- Modeling also the transients.
- Phase shifting reference functions
- latency mapping/modulation
- SE/GE ratios for localization
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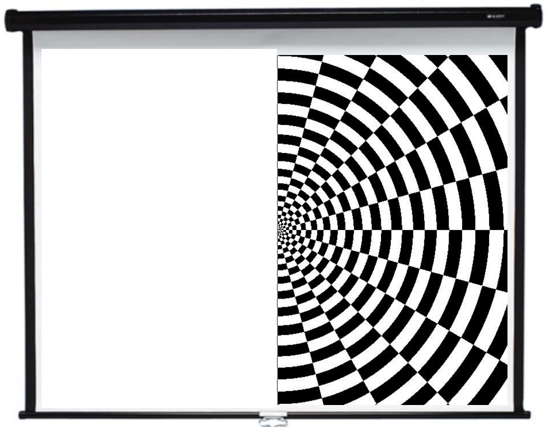
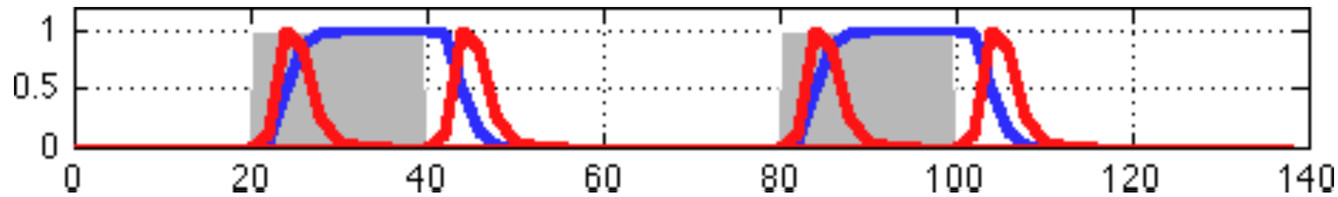
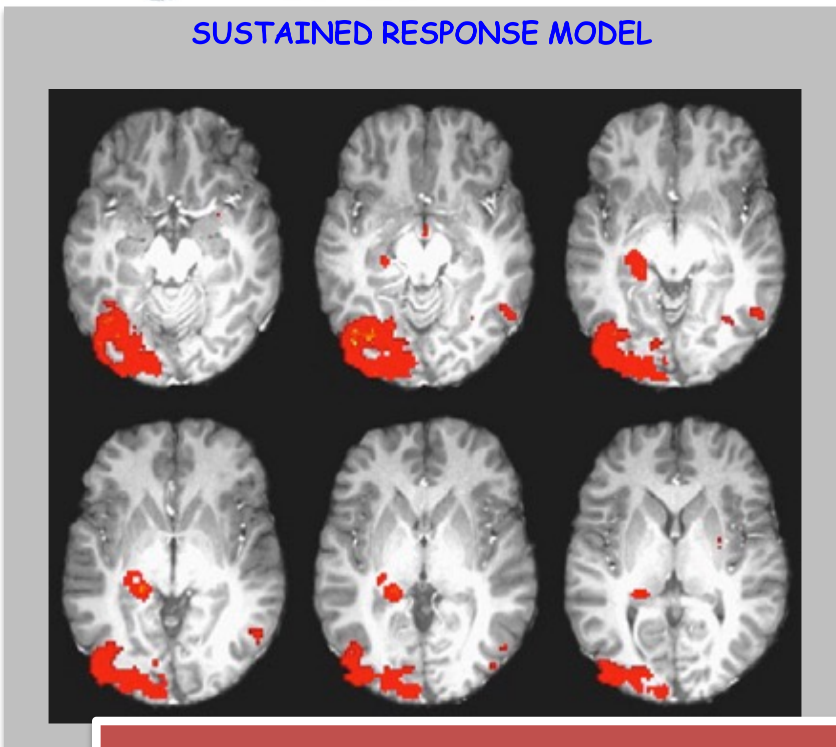
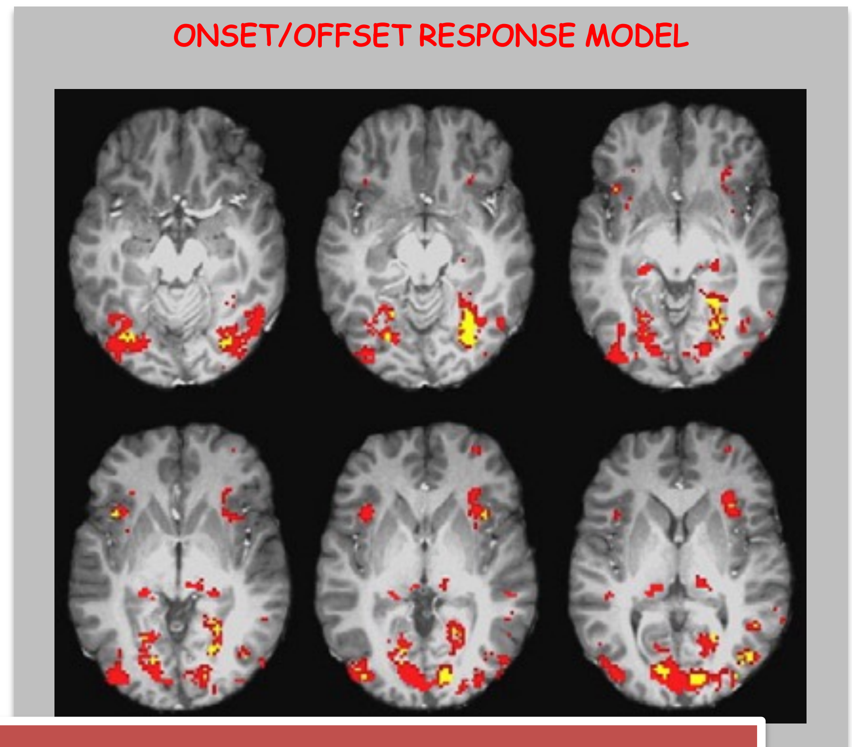
Using transients as regressors also.









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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