Recent Advances in Functional MRI

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

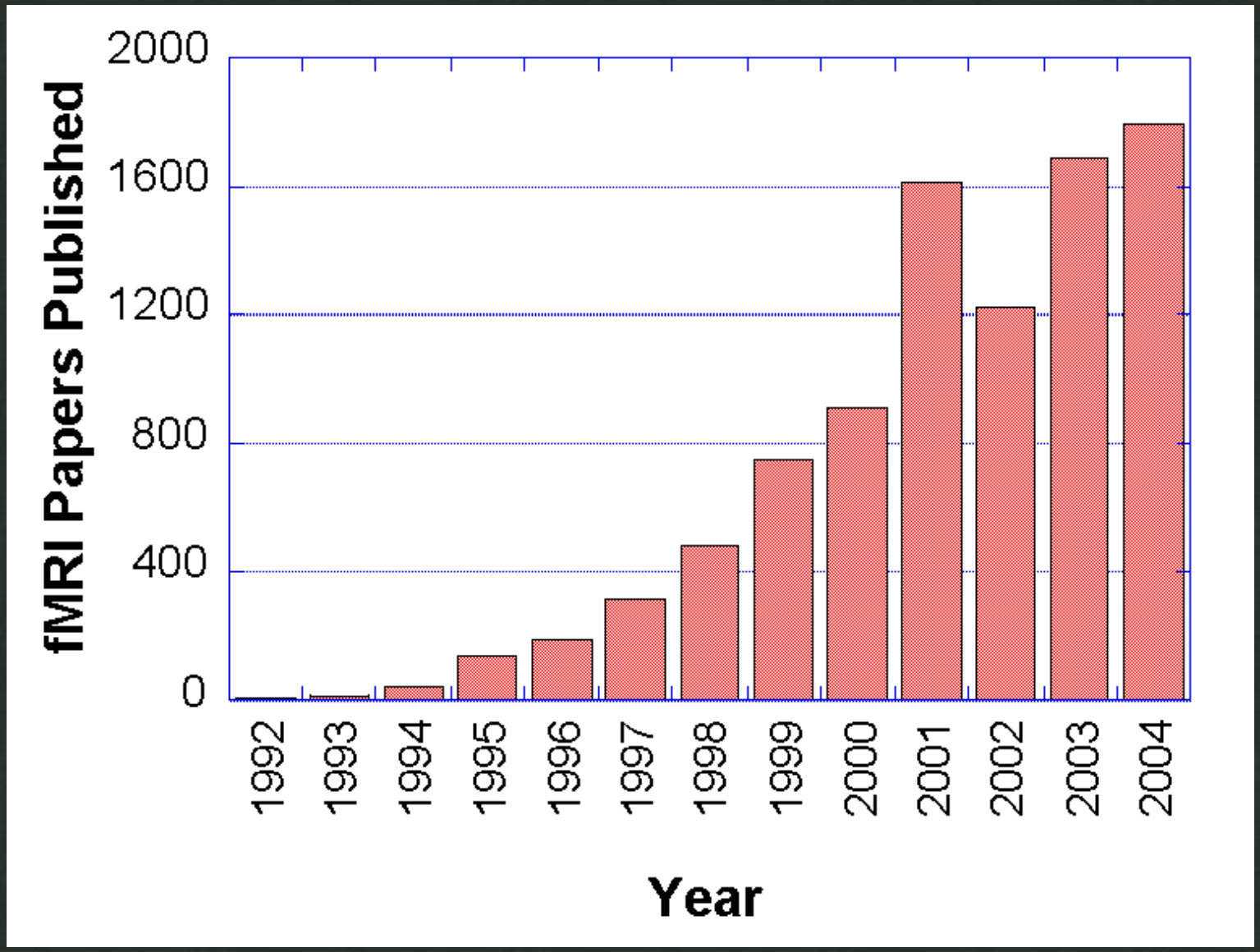
http://fim.nimh.nih.gov

Laboratory of Brain and Cognition

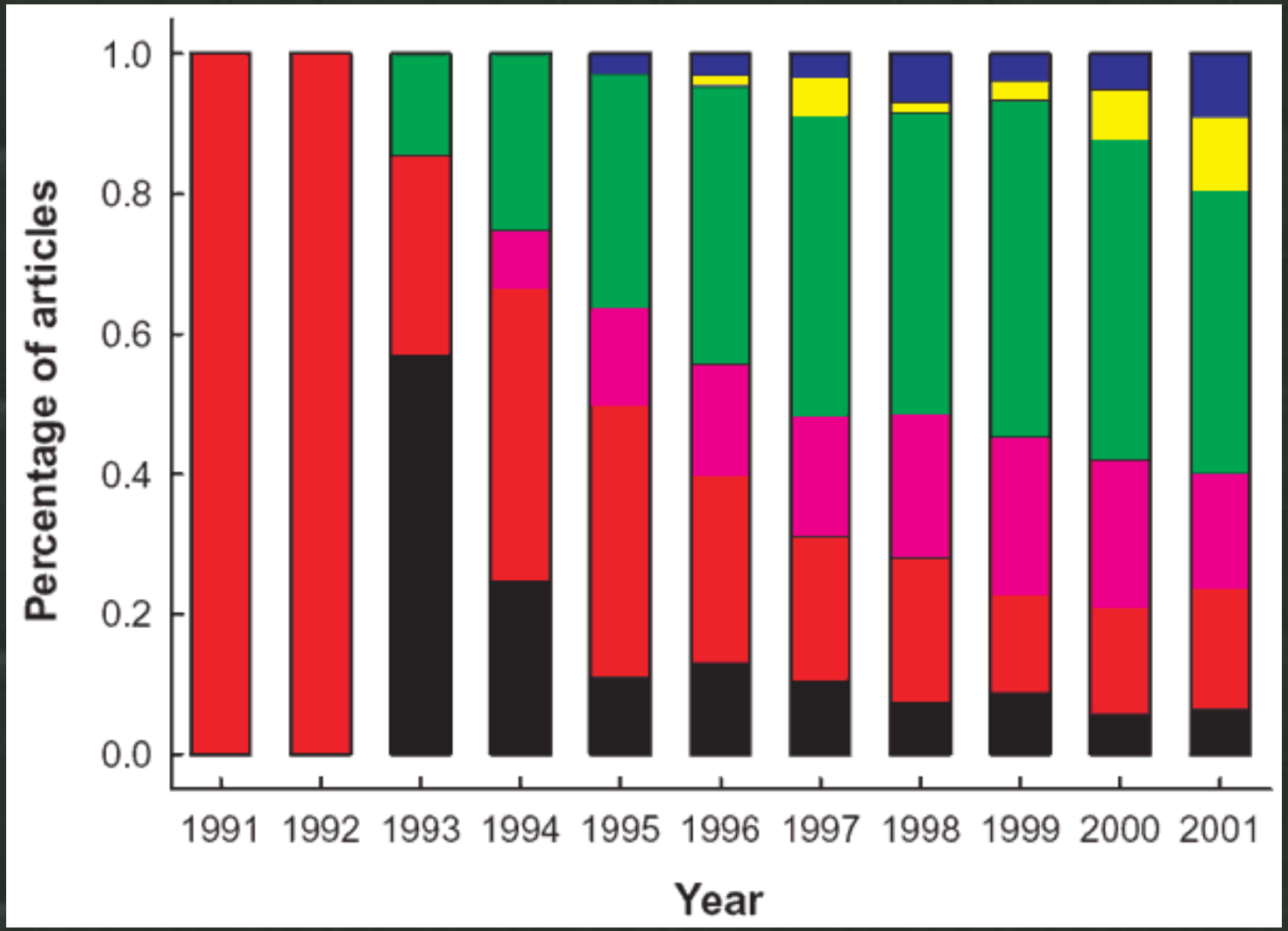
&

Functional MRI Facility

http://fmrif.nimh.nih.gov

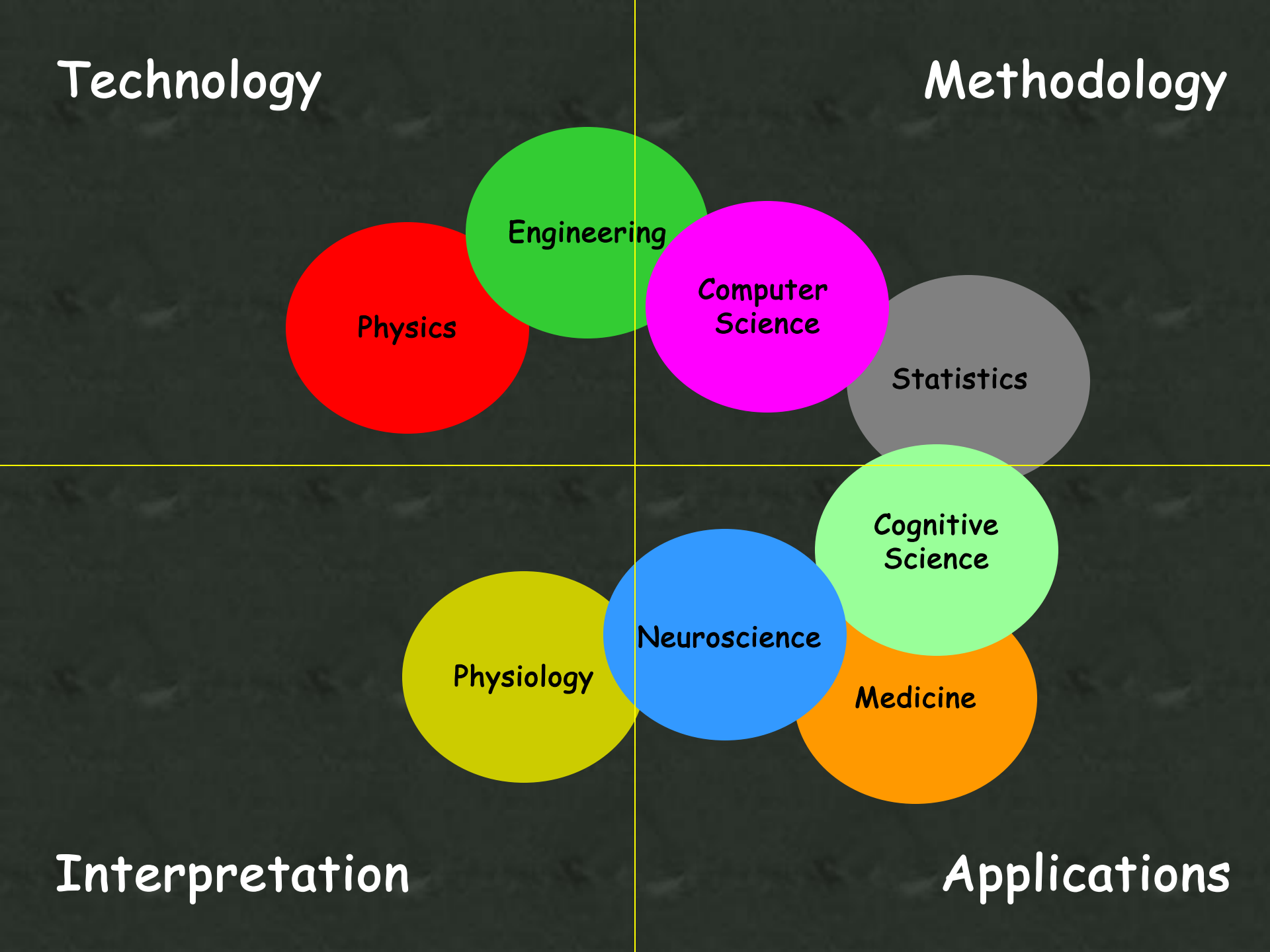


"fMRI" or "functional MRI"



Motor (black)
Primary Sensory (red)
Integrative Sensory (violet)
Basic Cognition (green)
High-Order Cognition (yellow)
Emotion (blue)

J. Illes, M. P. Kirschen, J. D. E. Gabrielli,
Nature Neuroscience, 6 (3)m p.205


Technology
Methodology
Engineering
Physics
Computer Science
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Neuroscience
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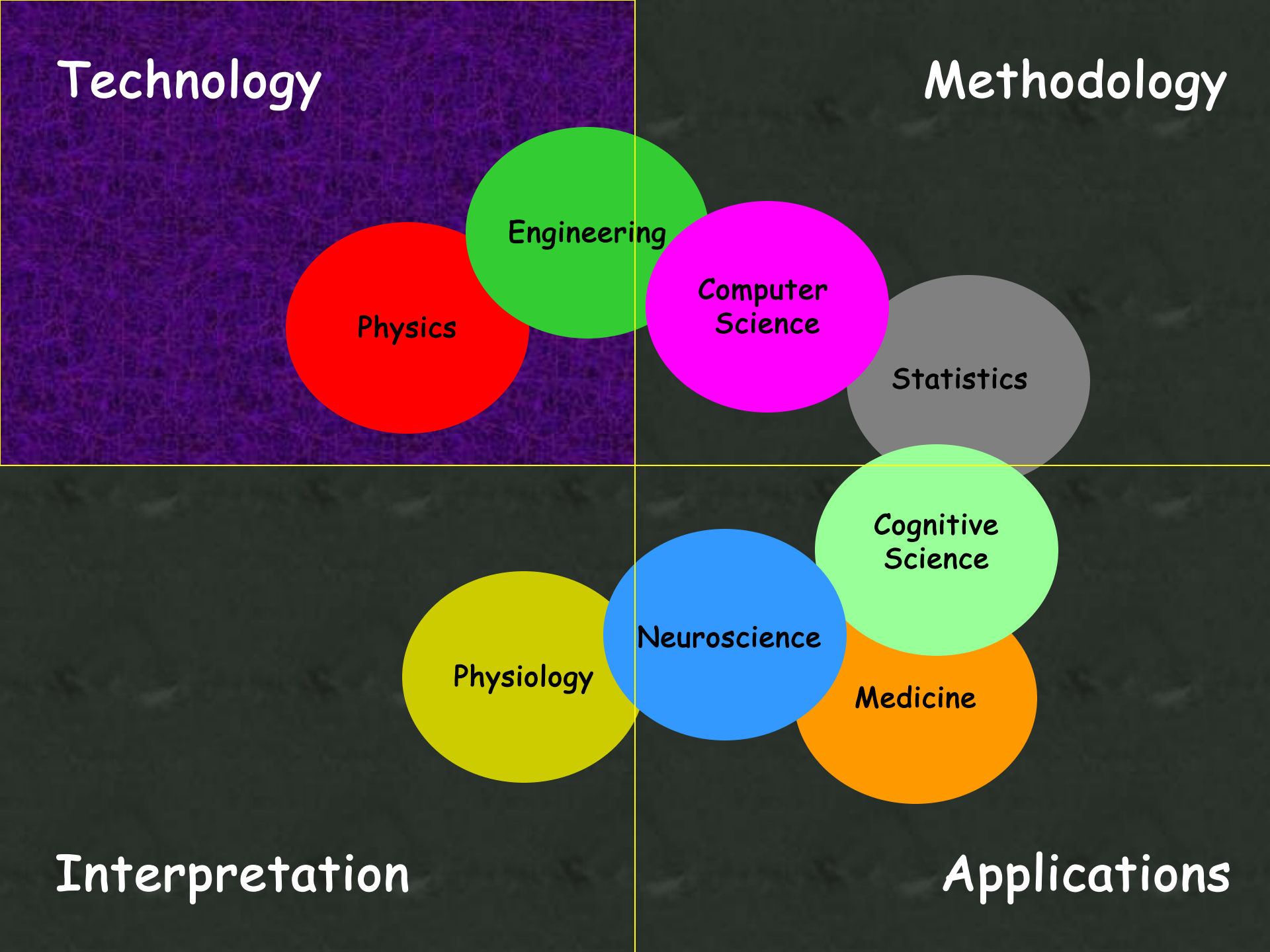
Medicine
Interpretation
Applications


Technology
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Applications

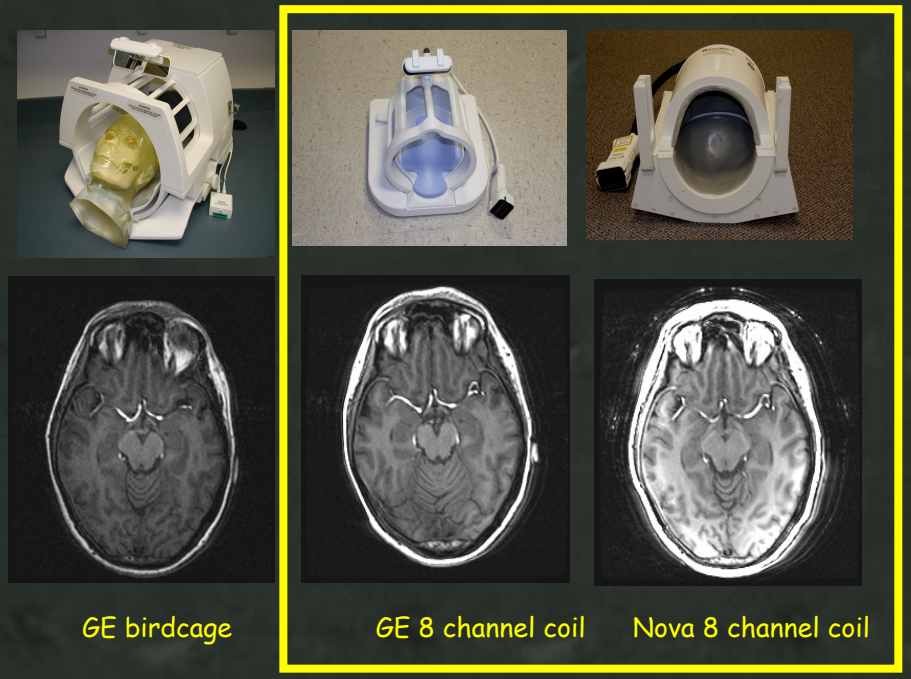
Technology

- Parallel Acquisition
- SENSE Imaging
- High Fields

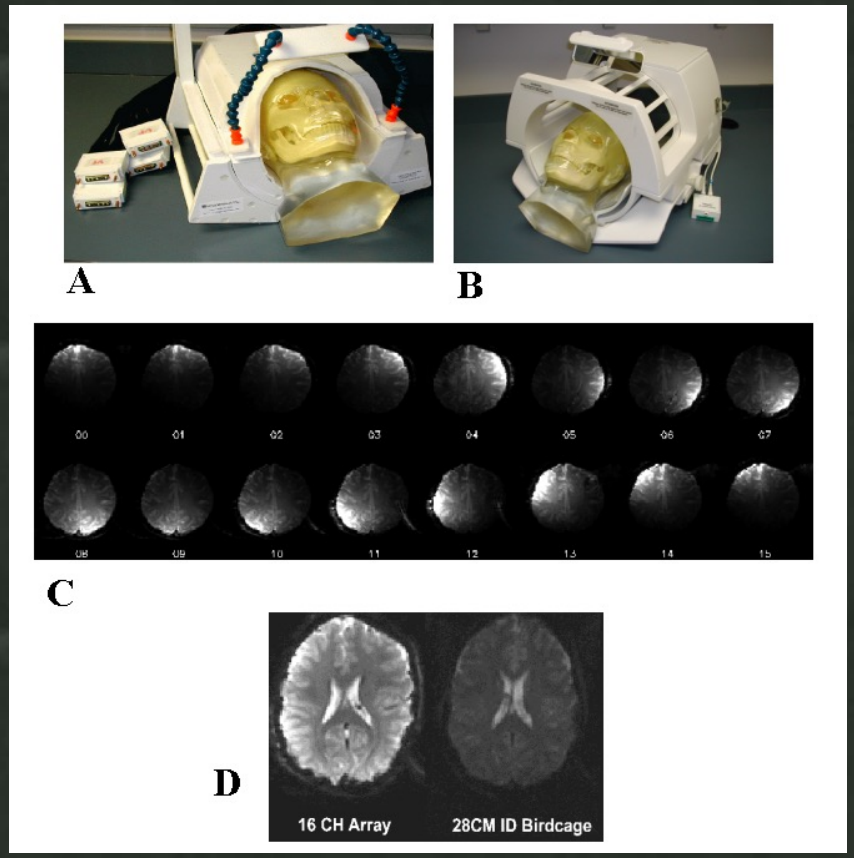
Technology

Parallel Acquisition

8 channel parallel receiver coil

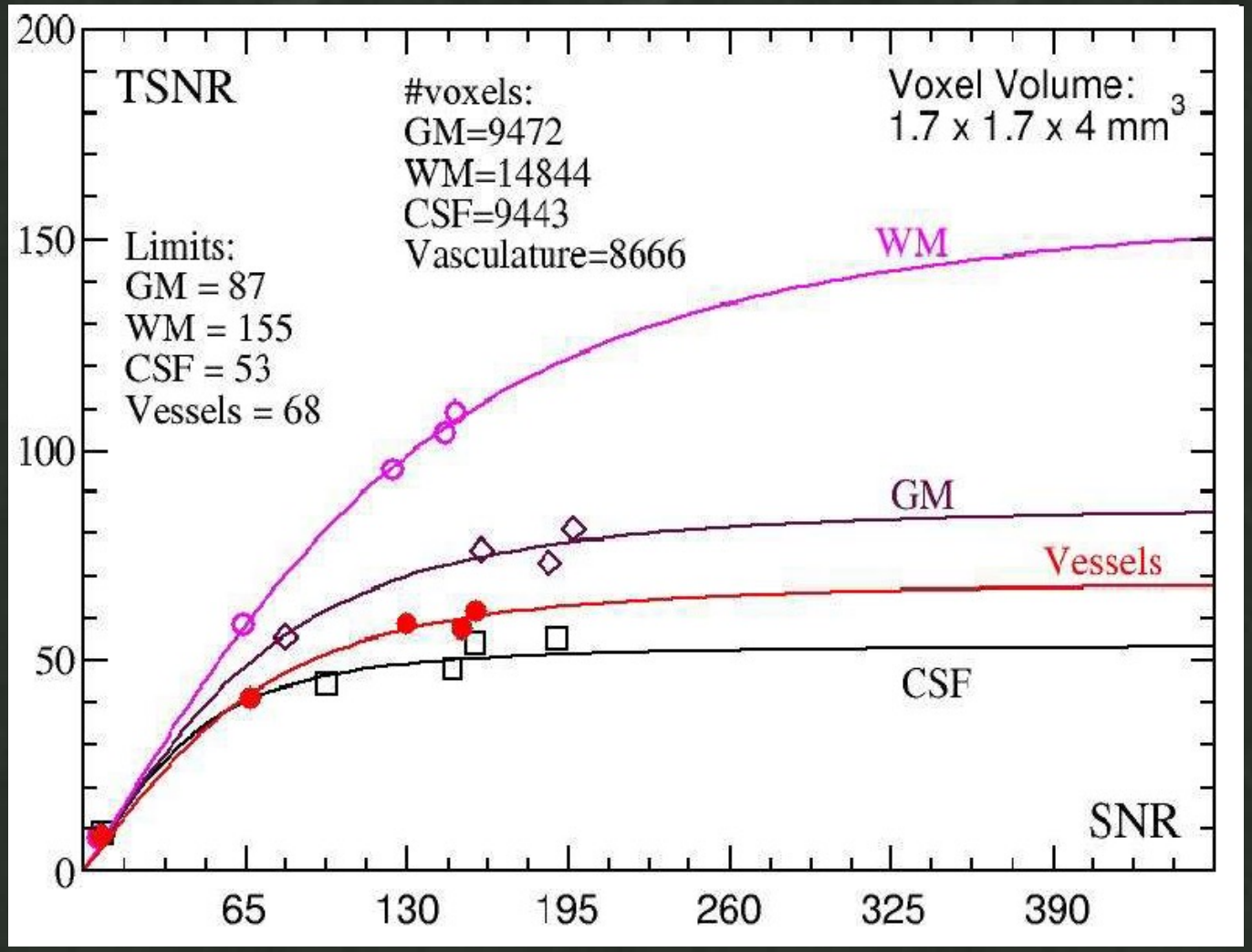


16 channel parallel receiver coil



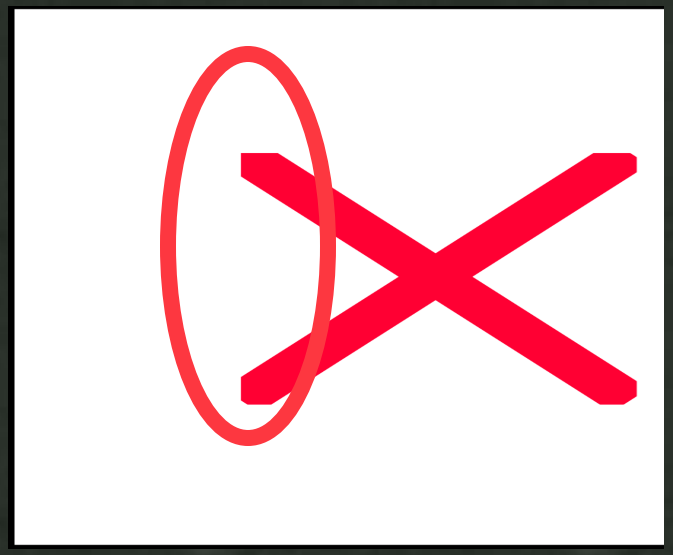
J. Bodurka, et al, Magnetic Resonance in Medicine 51 (2004) 165-171.

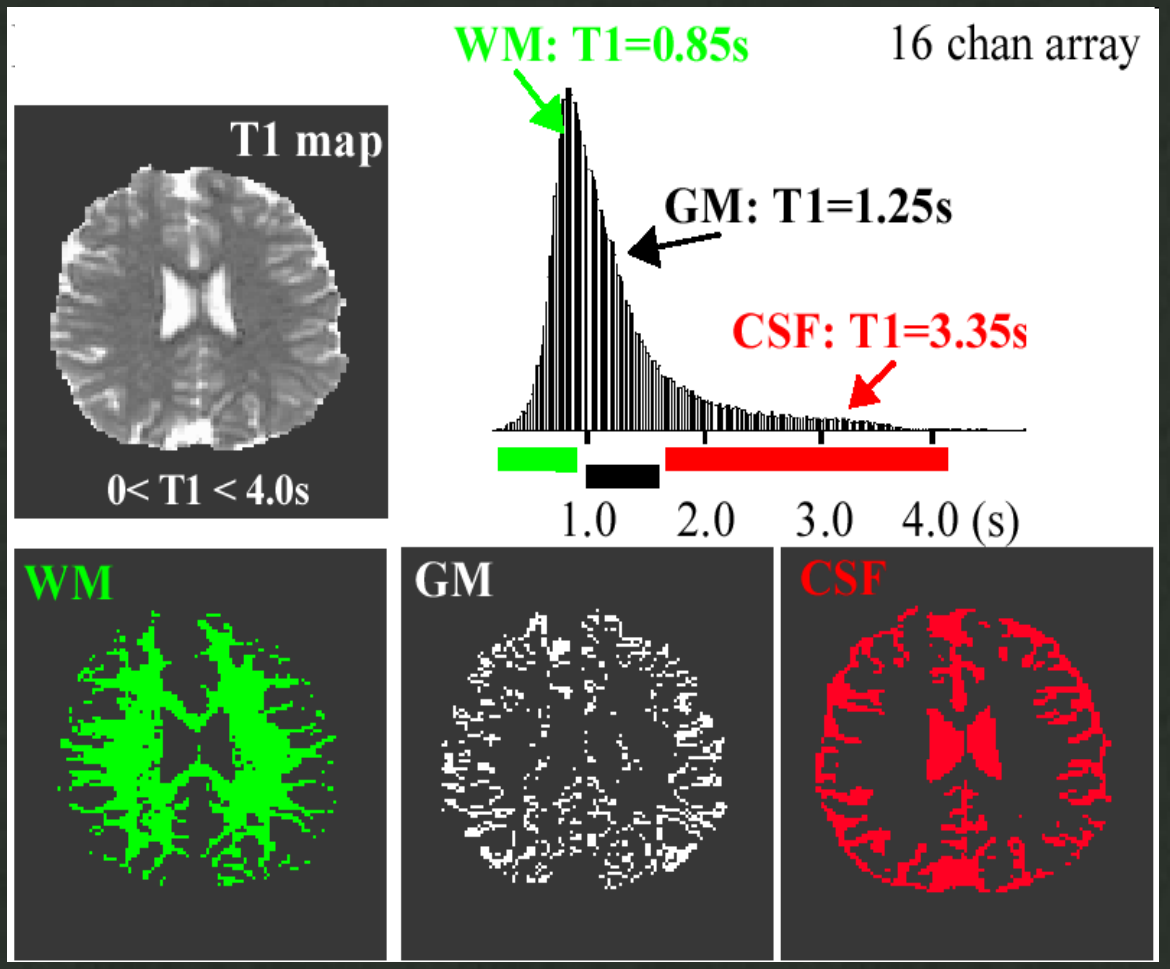
Parallel Acquisition



J. Bodurka

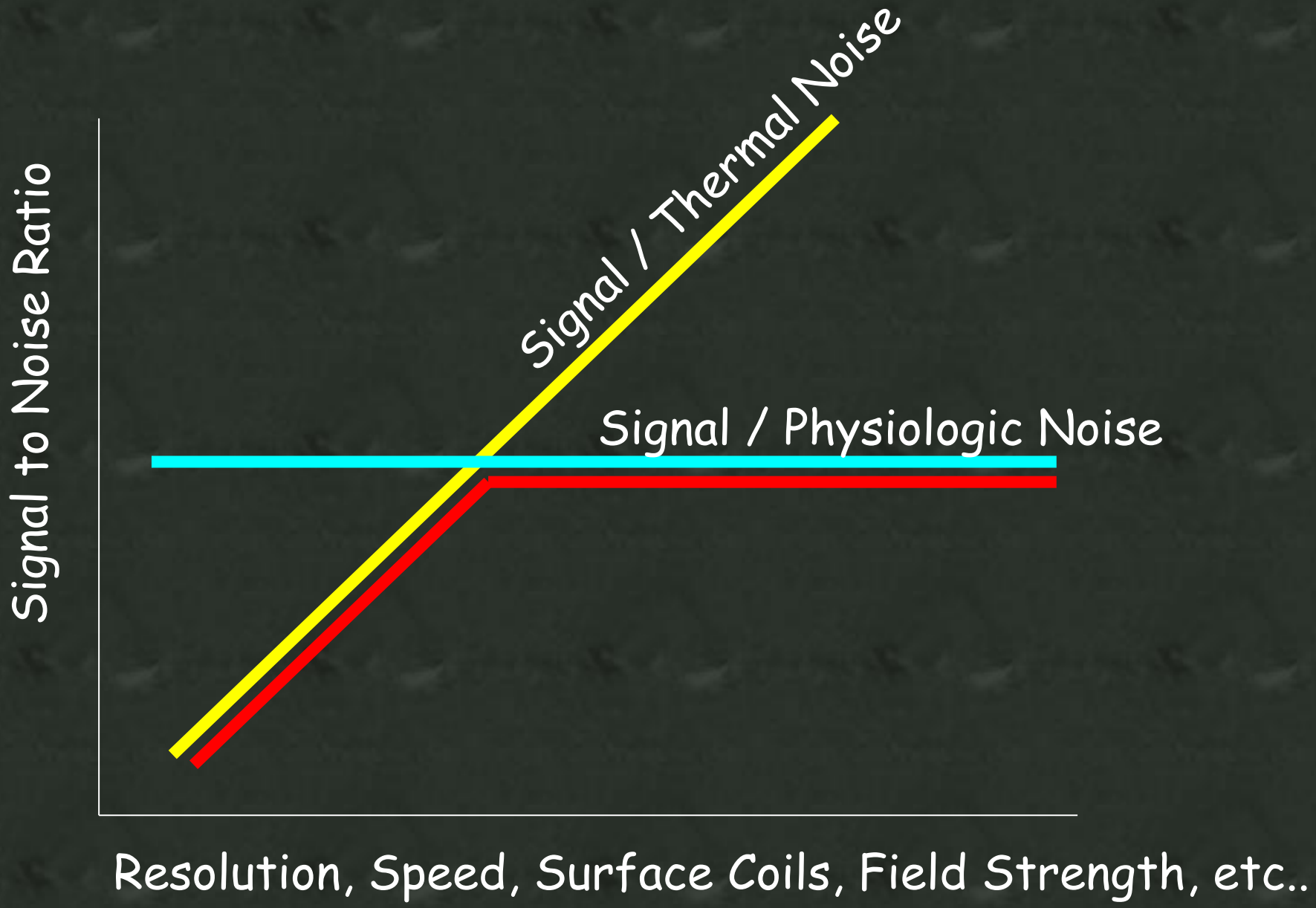
Segmentation using EPI Transient



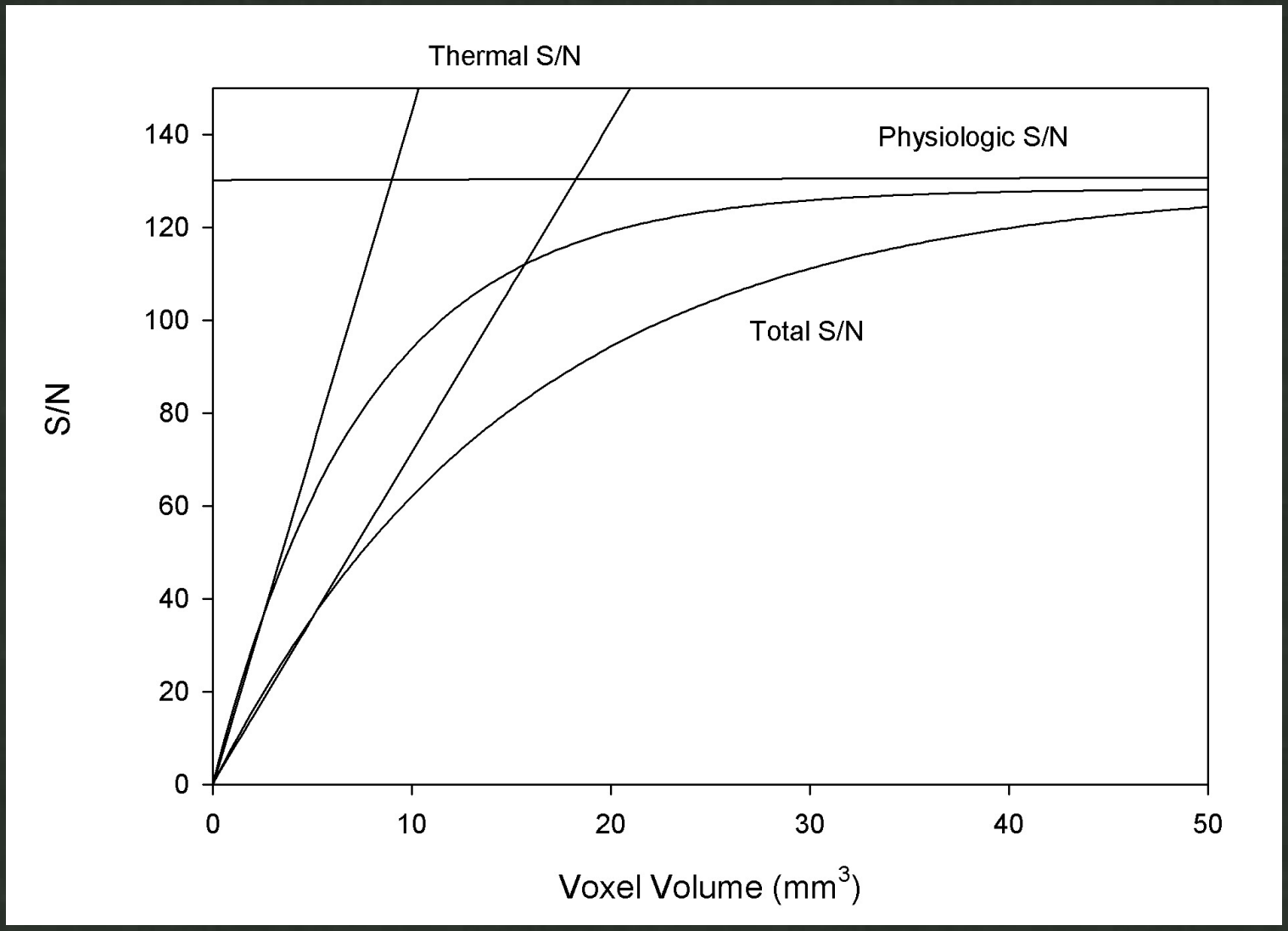


Technology

Parallel Acquisition

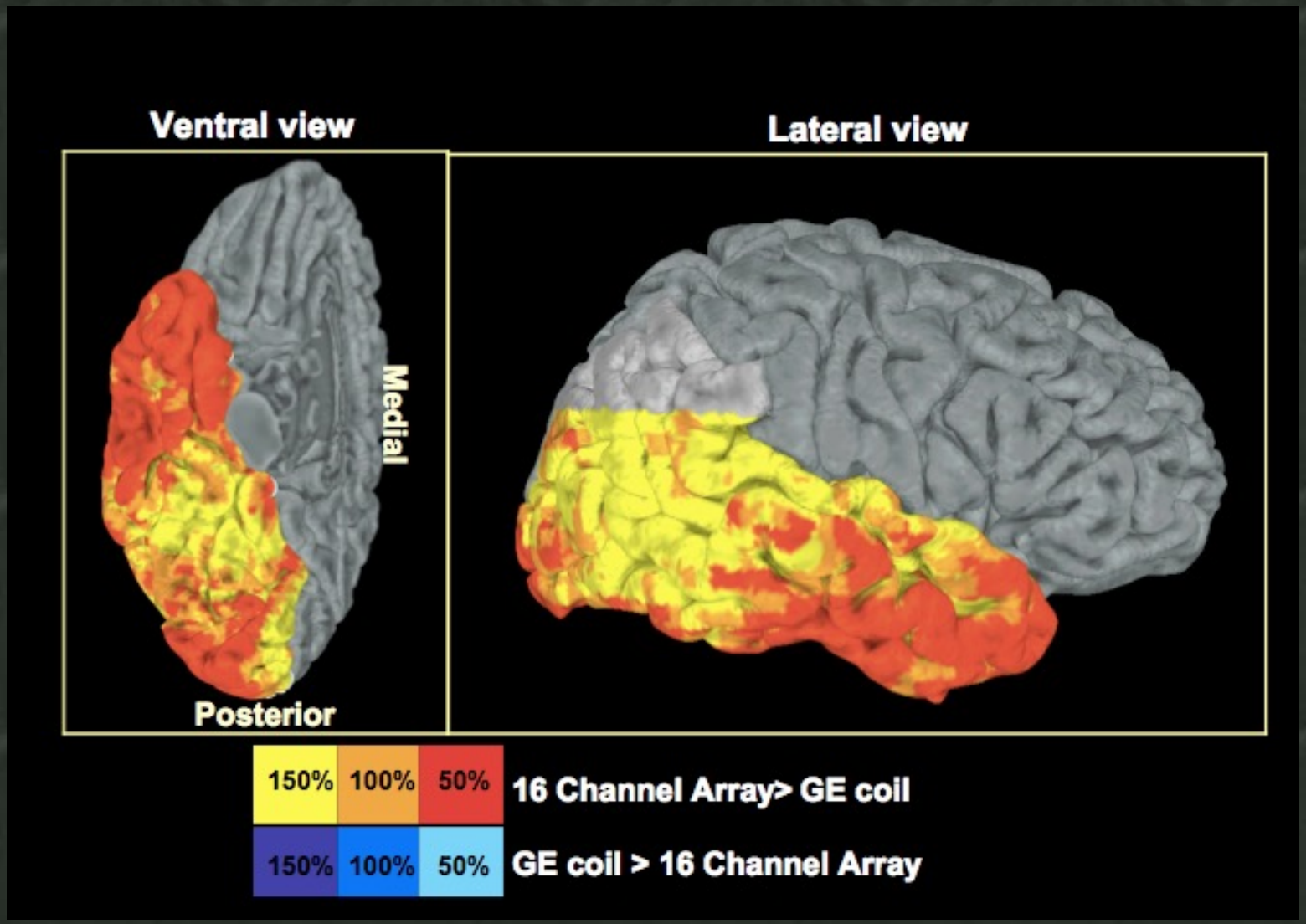


Simulated gains in TNSR with doubling sensitivity



Technology

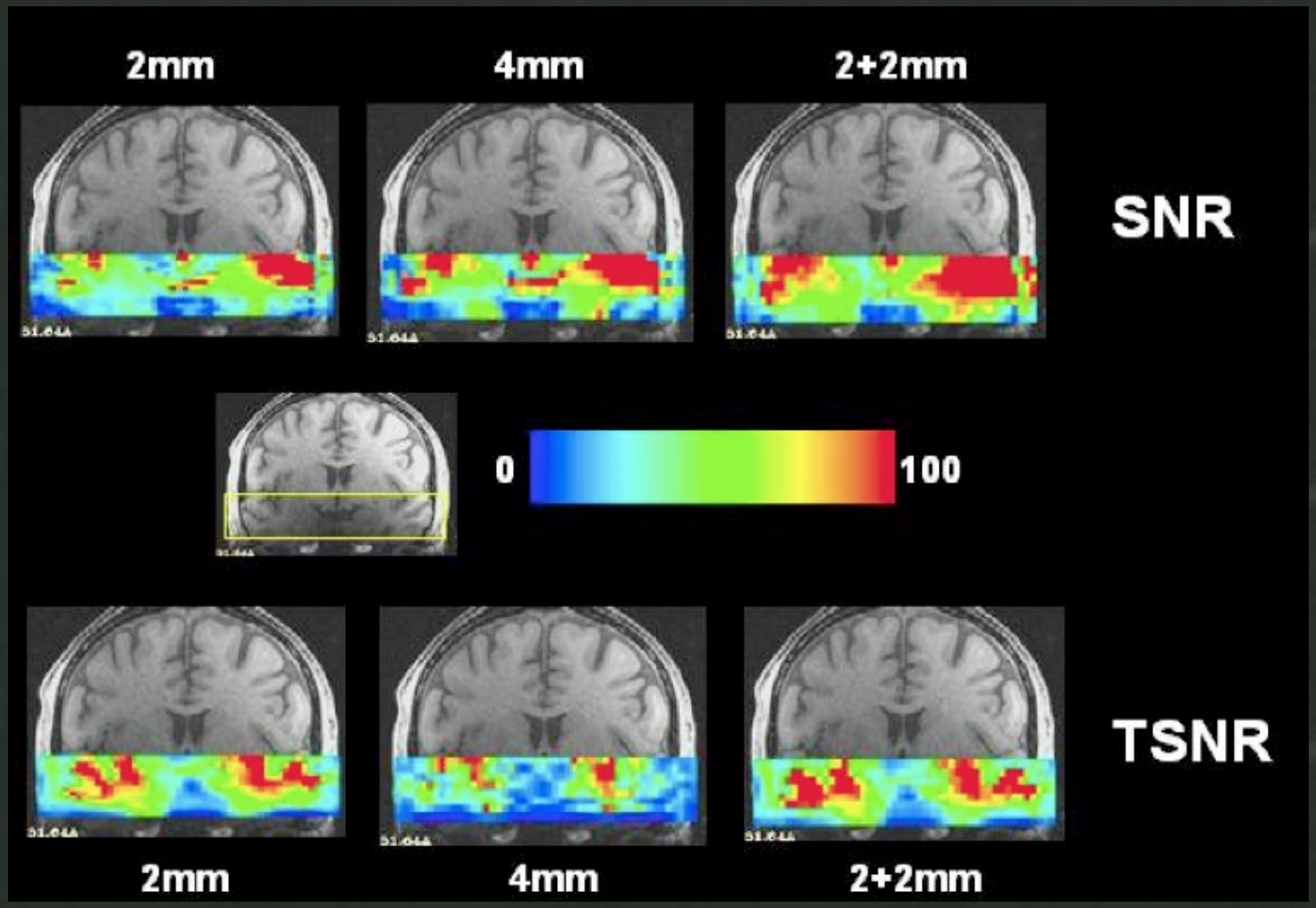
Parallel Acquisition



Bellgowan et al.

Technology

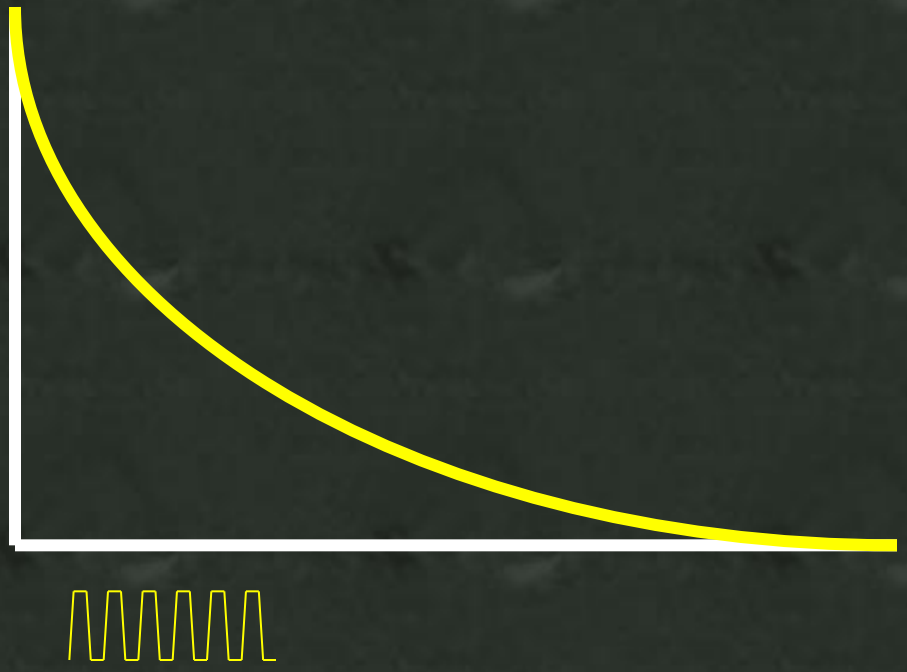
Parallel Acquisition



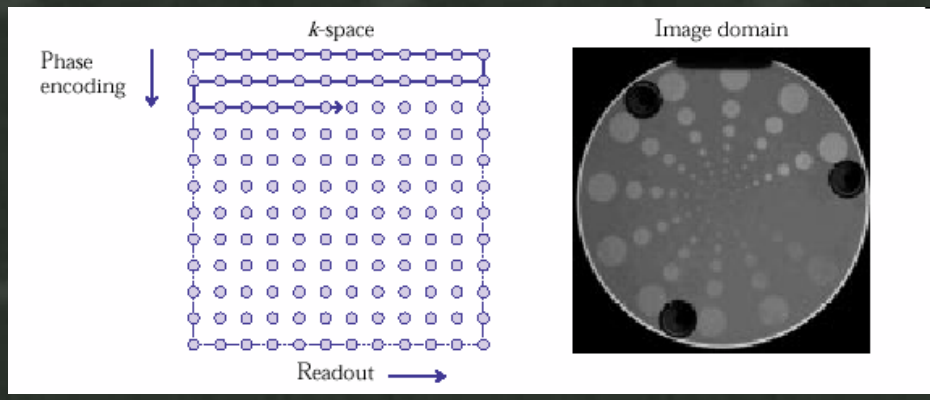
Bellgowan et al.

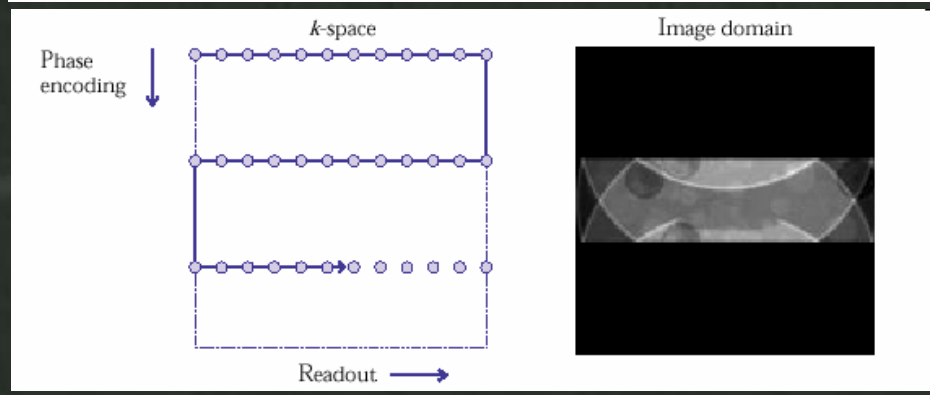
Technology

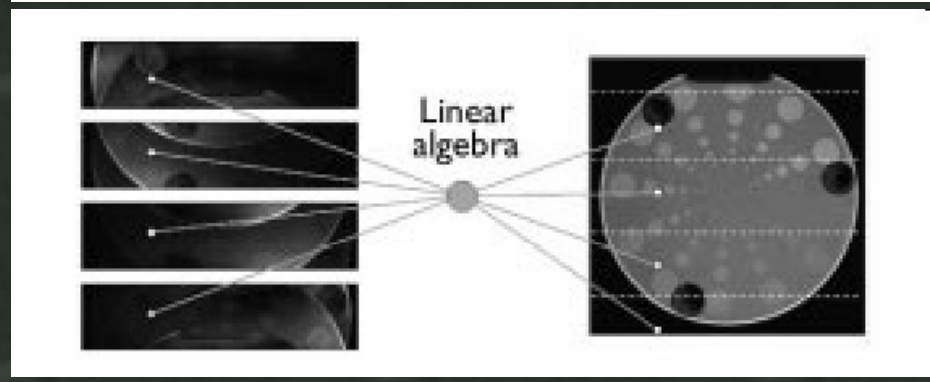
SENSE Imaging



≈ 5 to 30 ms







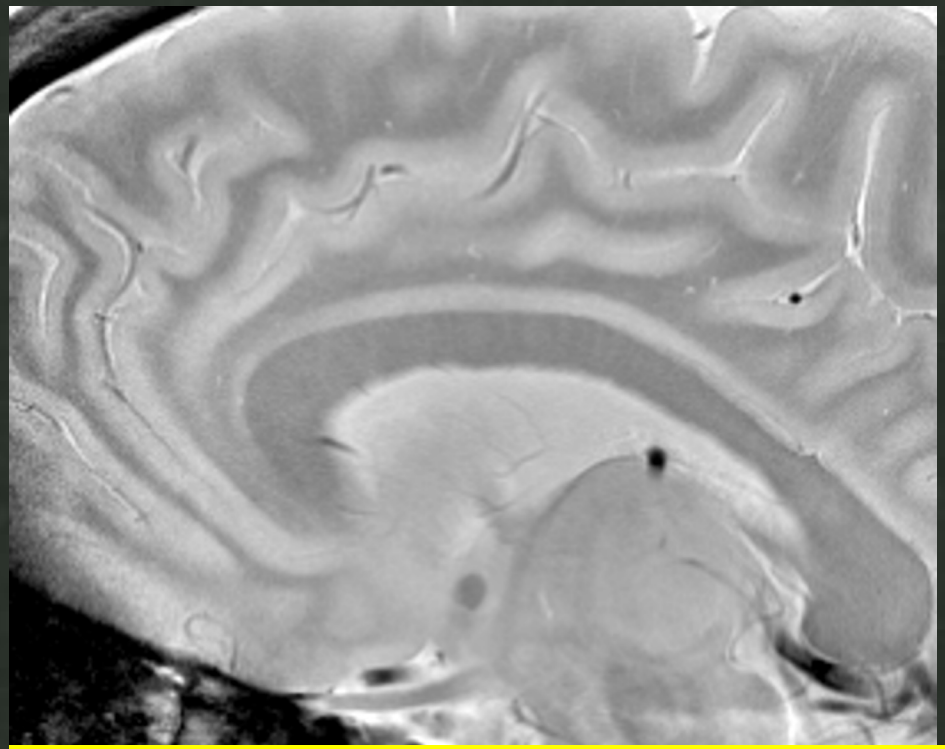
Pruessmann, et al.

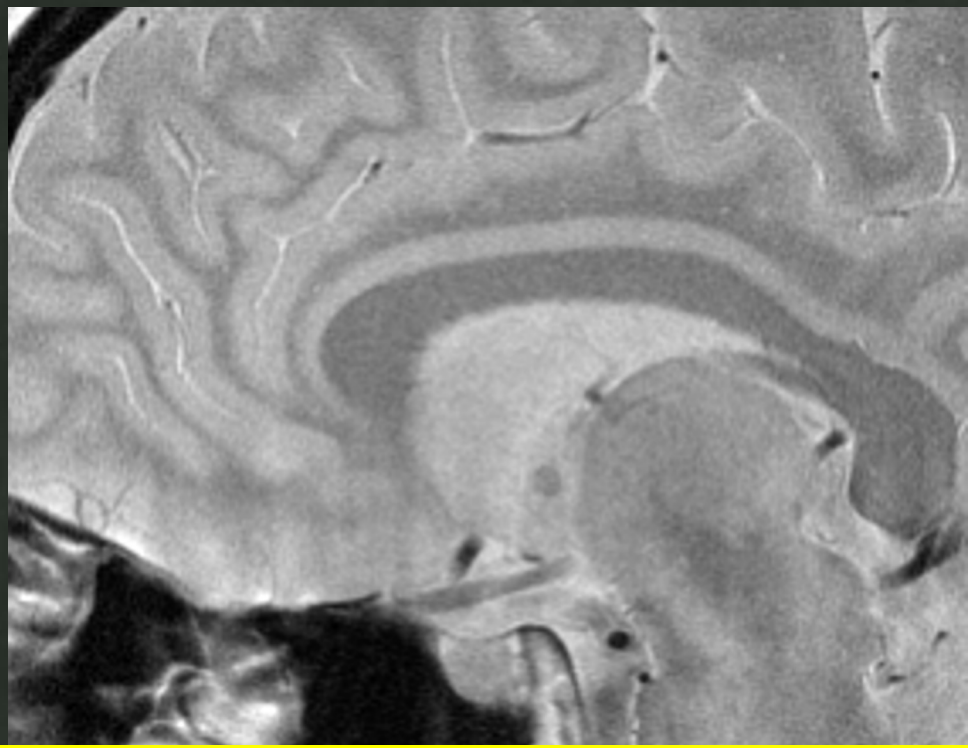
SENSE Imaging

3T single-shot SENSE EPI using 16 channels: 1.25x1.25x2mm

7T head coil

3T head coil





TSE, 11 echoes, 7 min exam, 20cm FOV, 512x512 (0.4mm x 0.4mm), 3mm thick slices.

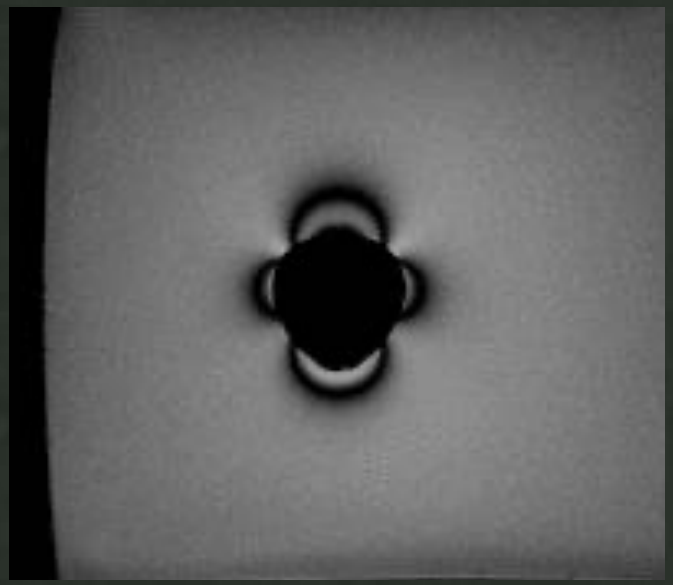
7T
white matter SNR =65
Gray matter SNR = 76

3T
white matter SNR =26
Gray matter SNR = 34

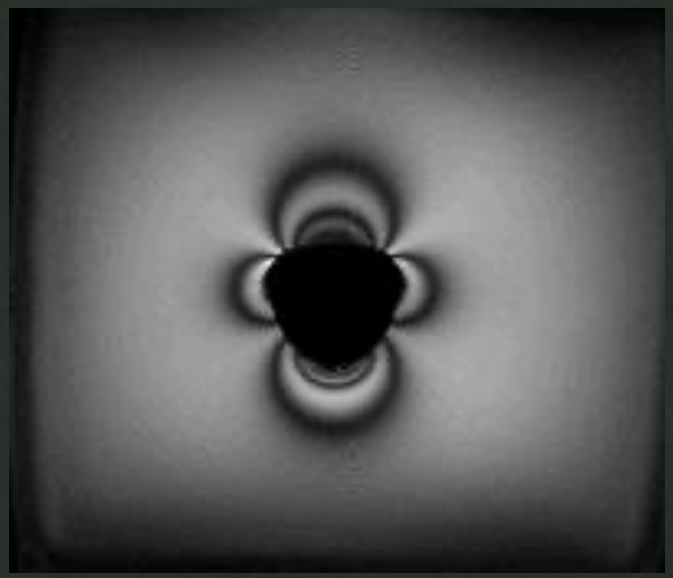
Courtesy Larry Wald

Susceptibility field (in Gauss) increases w/ B_o

Ping-pong ball in H_2O:
Field maps (DTE = 5ms), black lines spaced by 0.024G (0.8ppm at 3T)



1.5T

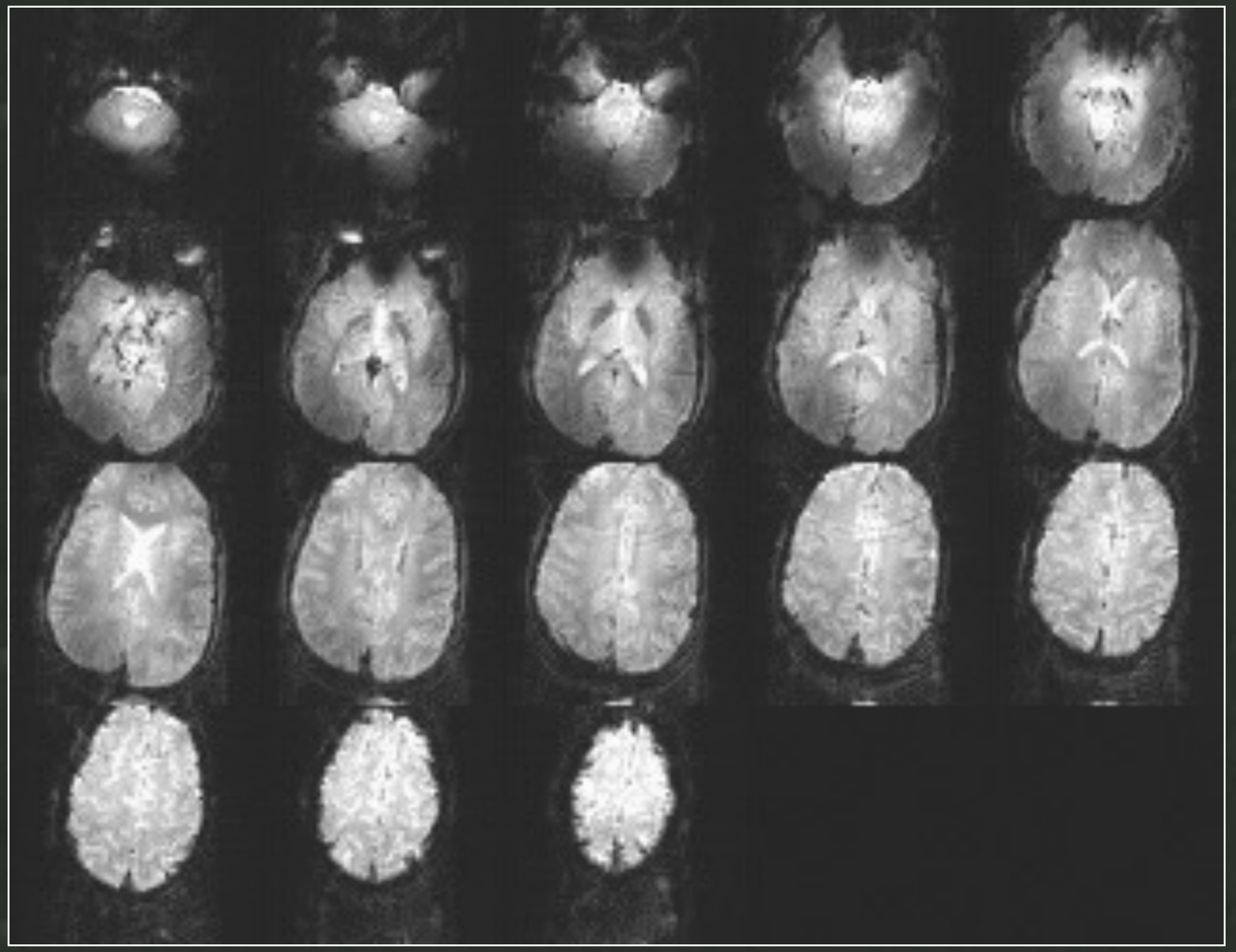


3T

7T

Courtesy Larry Wald

7T: Single Shot whole head EPI



3mm isotropic

single shot EPI, 7T.

64x64, 19cm FOV(3mm resolution), 3mm slice.

TE=20ms

Courtesy Larry Wald

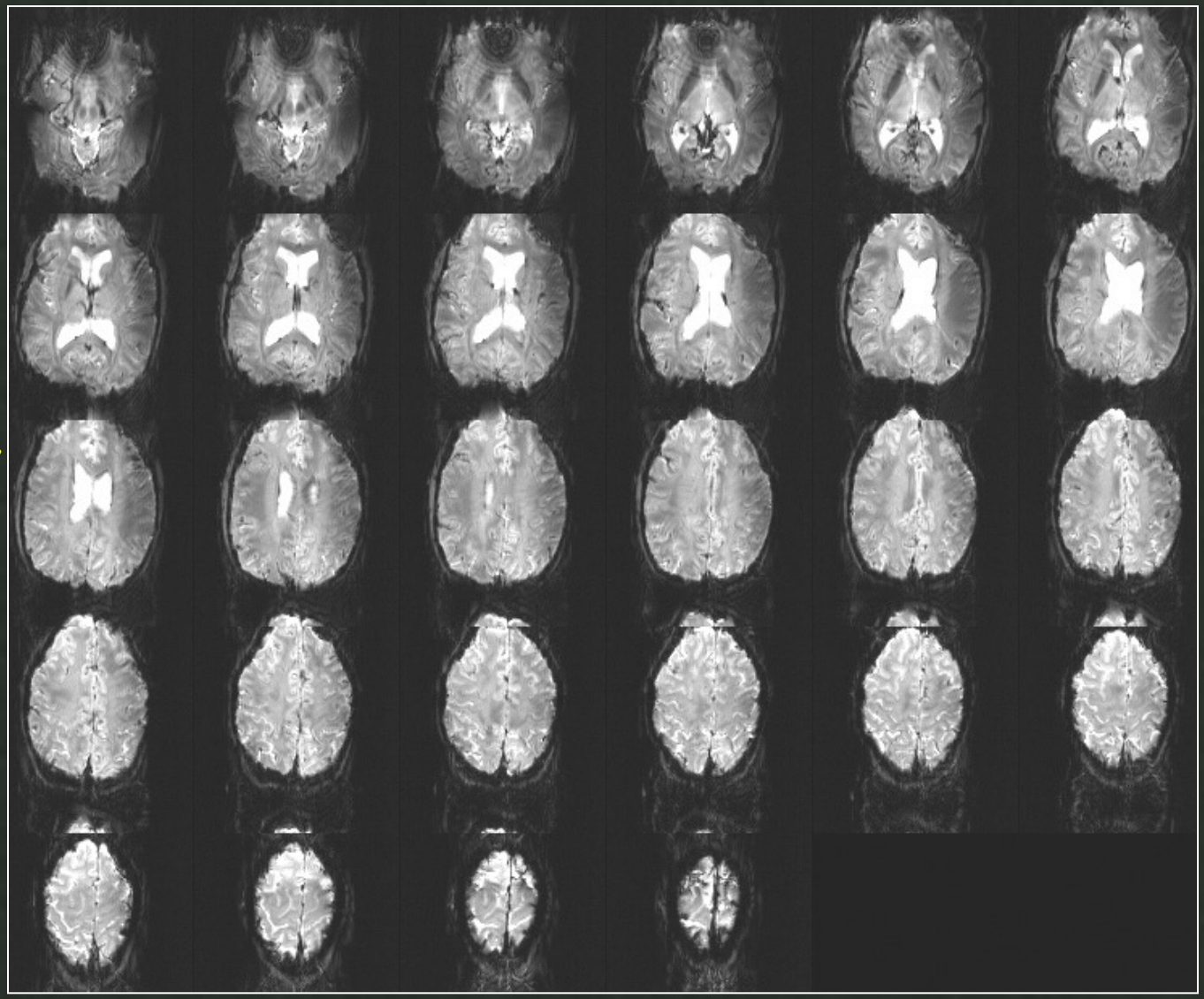
7T: Single Shot whole head EPI

1.5mm inplane

single shot EPI, 7T.

128x128, 20cm FOV (1.5mm resolution), 2mm slice,

TE = 20ms



Courtesy Larry Wald

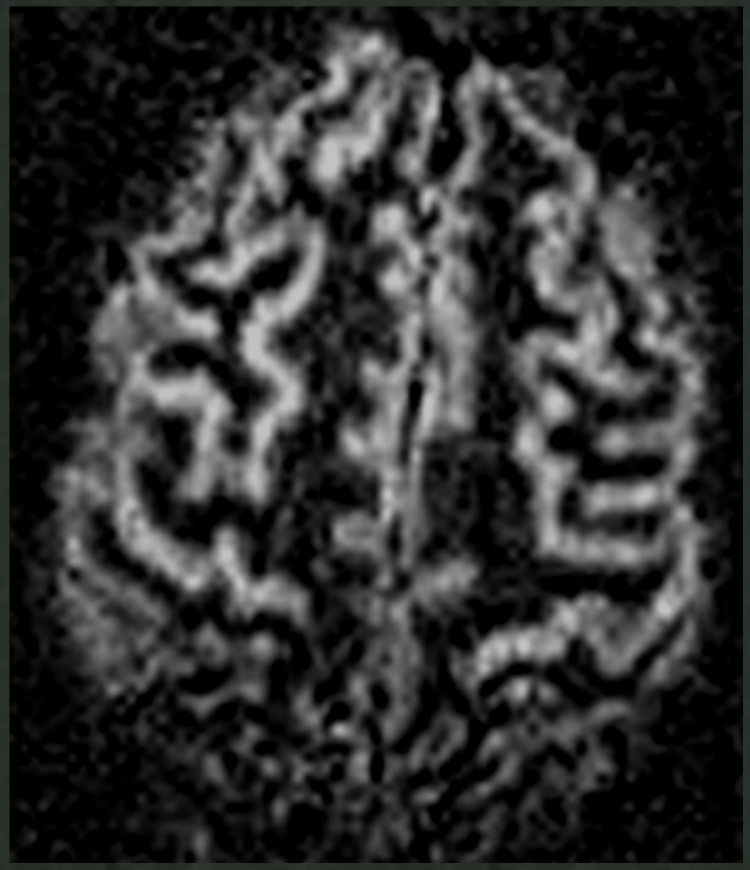
7T Blood flow and BOLD based fMRI

Longer T1 means better ASL…

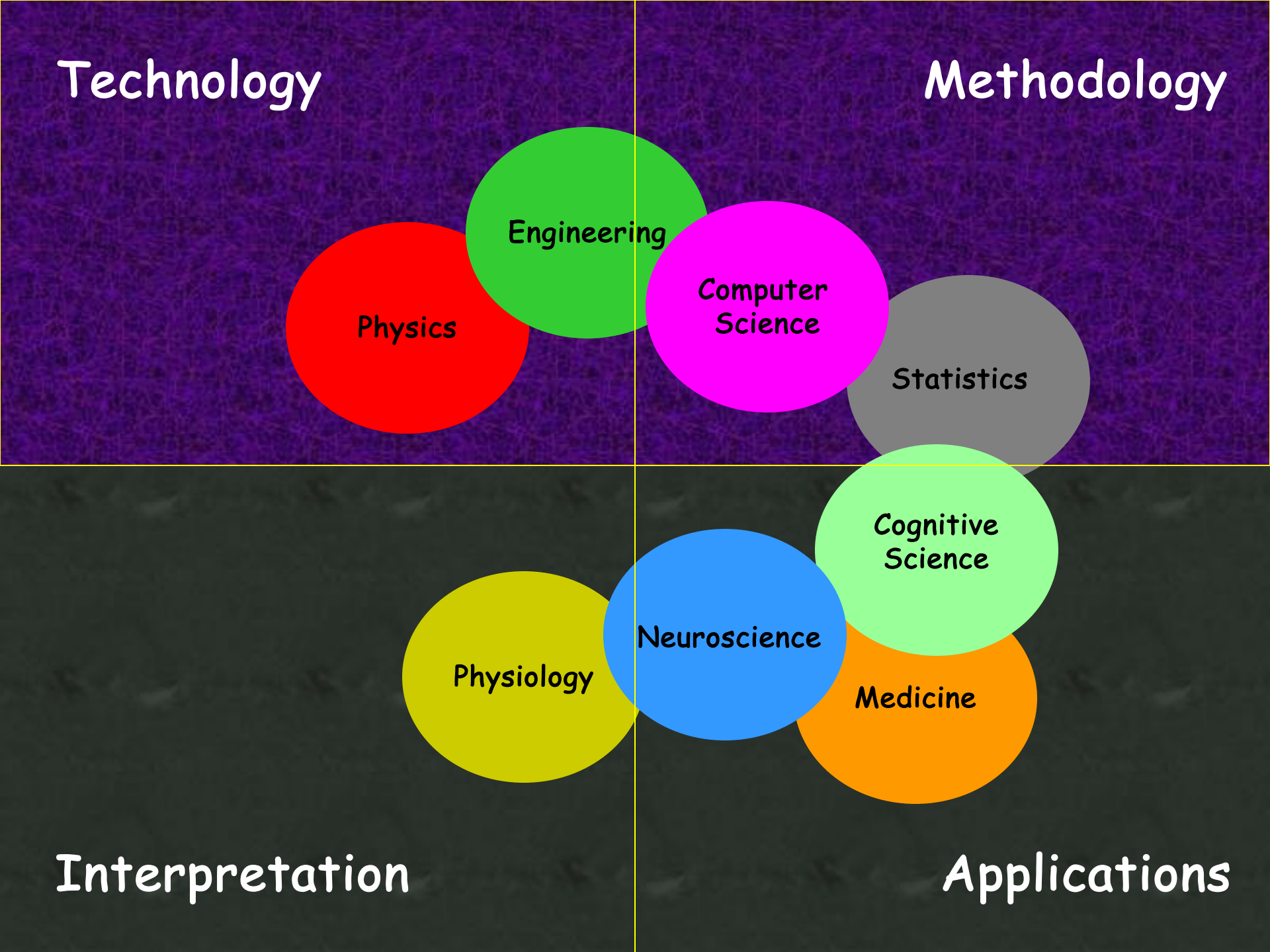
6 minute pulse Arterial Spin Labeling blood flow image

1.56mm x 1.56mm x 4mm

(3T typical resolution: 3mmx 3mm x 5mm)



Courtesy Larry Wald


Technology
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Methodology

- New Contrasts
- Paradigm Designs
- Temporal Resolution
- Spatial Resolution
- Processing Methods

fMRI Contrast

- Volume (gadolinium)
- BOLD
- Perfusion (ASL)
- $\Delta CMRO_2$
- ΔVolume (VASO)
- Neuronal Currents
- Diffusion coefficient
- Temperature

fMRI Contrast

- Volume (gadolinium)
- BOLD
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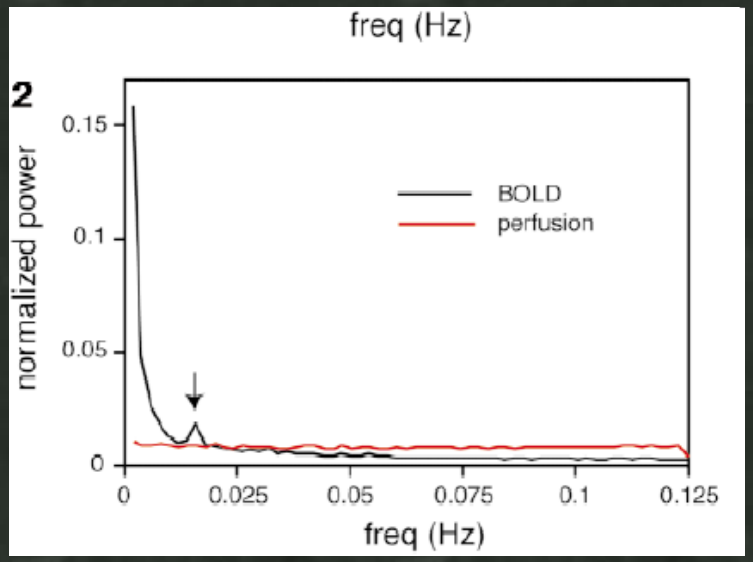
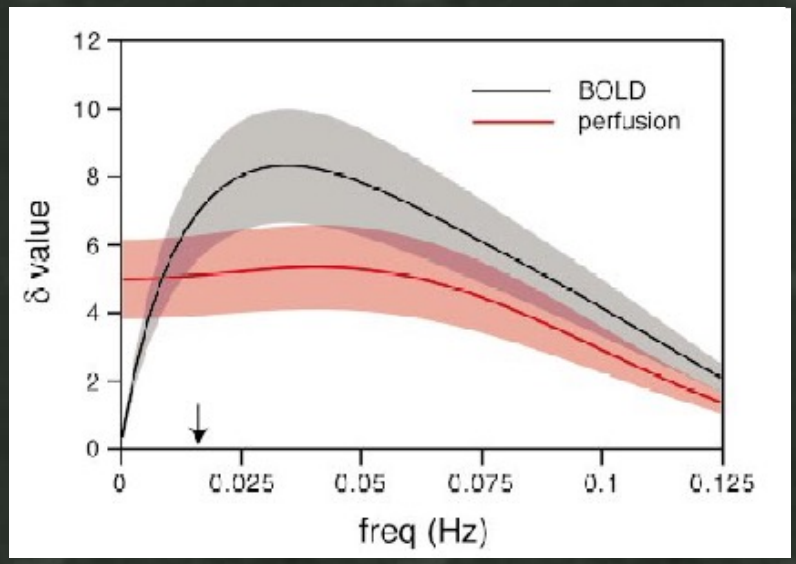
- Neuronal Currents
- Diffusion coefficient
- Temperature

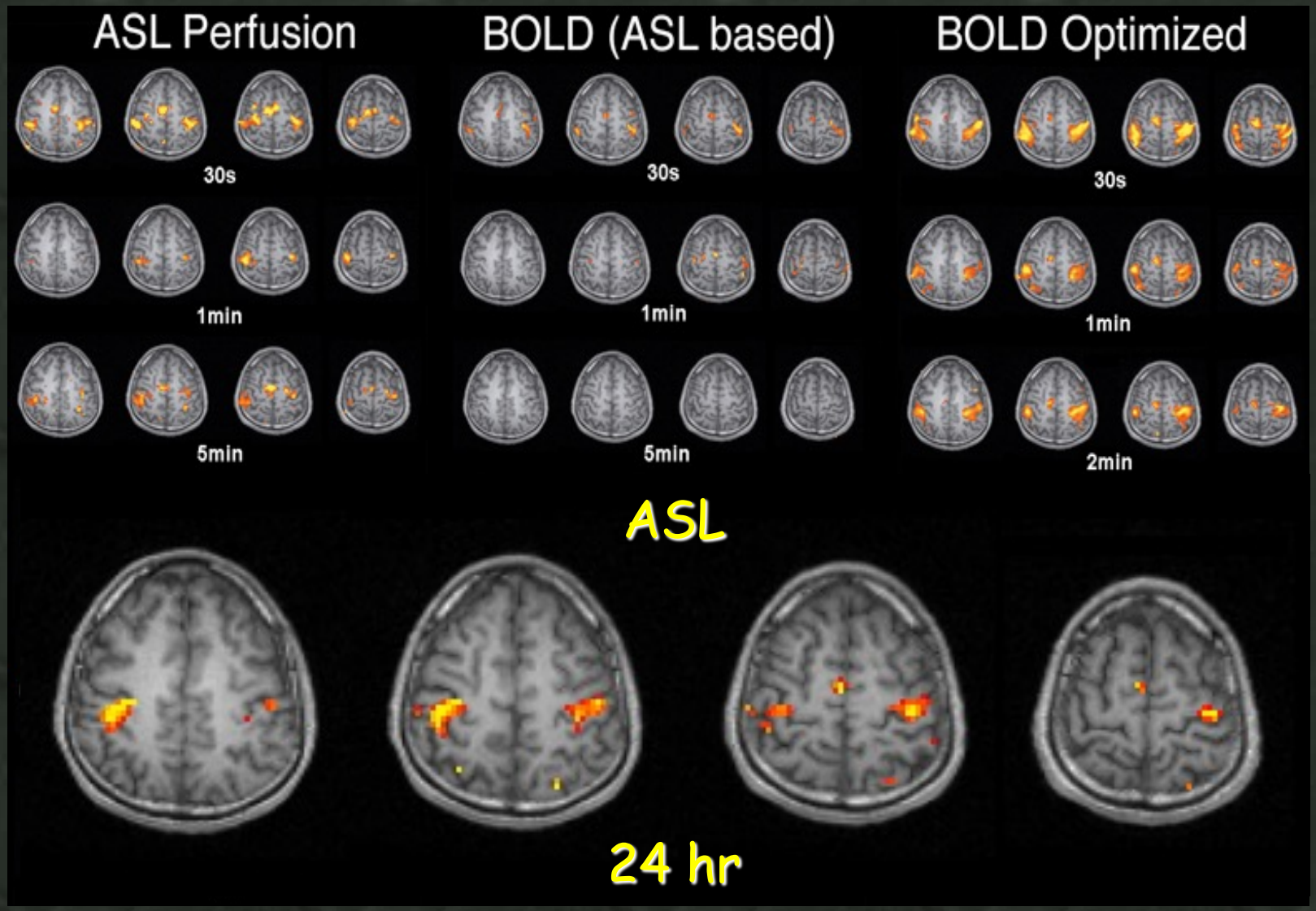
Better than BOLD for long duration activation…





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

Perfusion vs. BOLD: Low Task Frequency



Wang et al., 2002

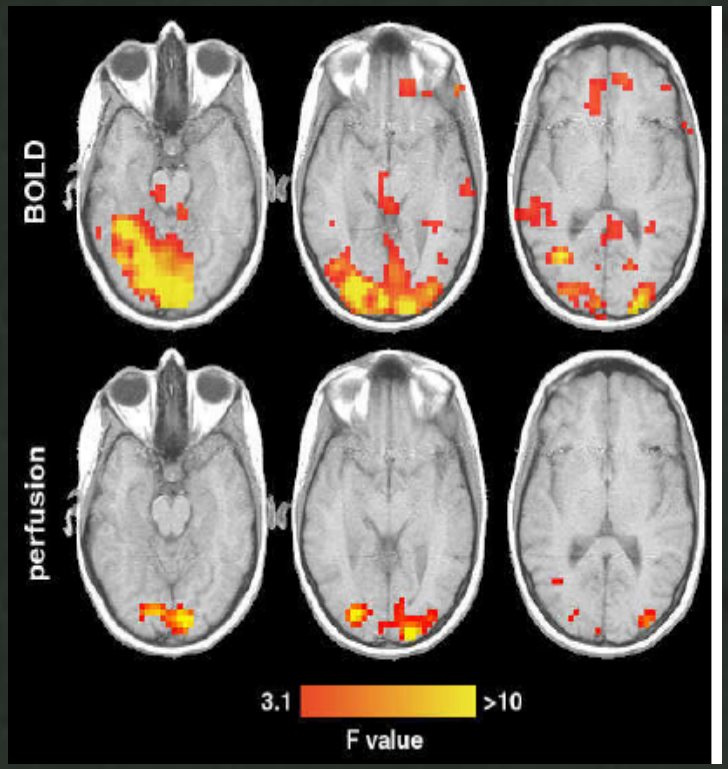
Methodology

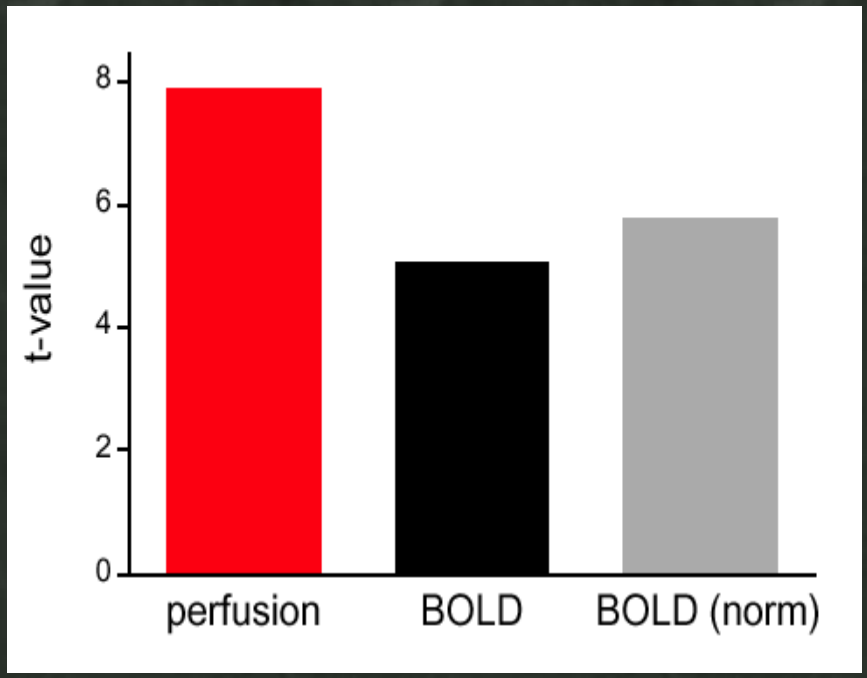
New Contrasts

Perfusion (ASL)

ASL Perfusion fMRI vs. BOLD

Improved Intersubject Variability vs. BOLD





Single Subject

Group (Random Effects)

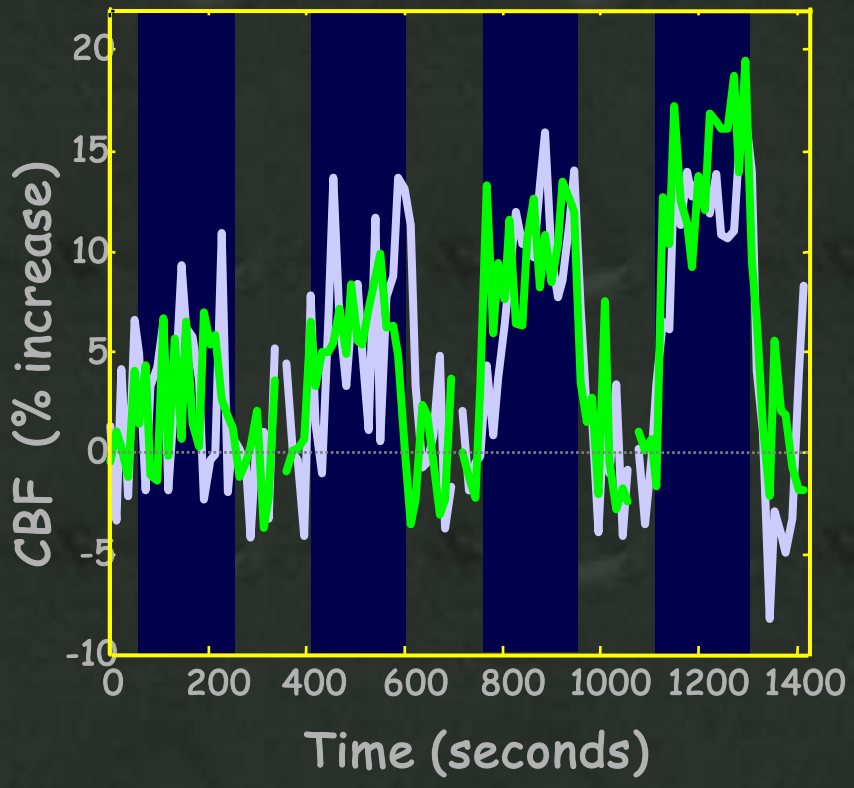
Aguirre et al., NeuroImage, in press

Methodology

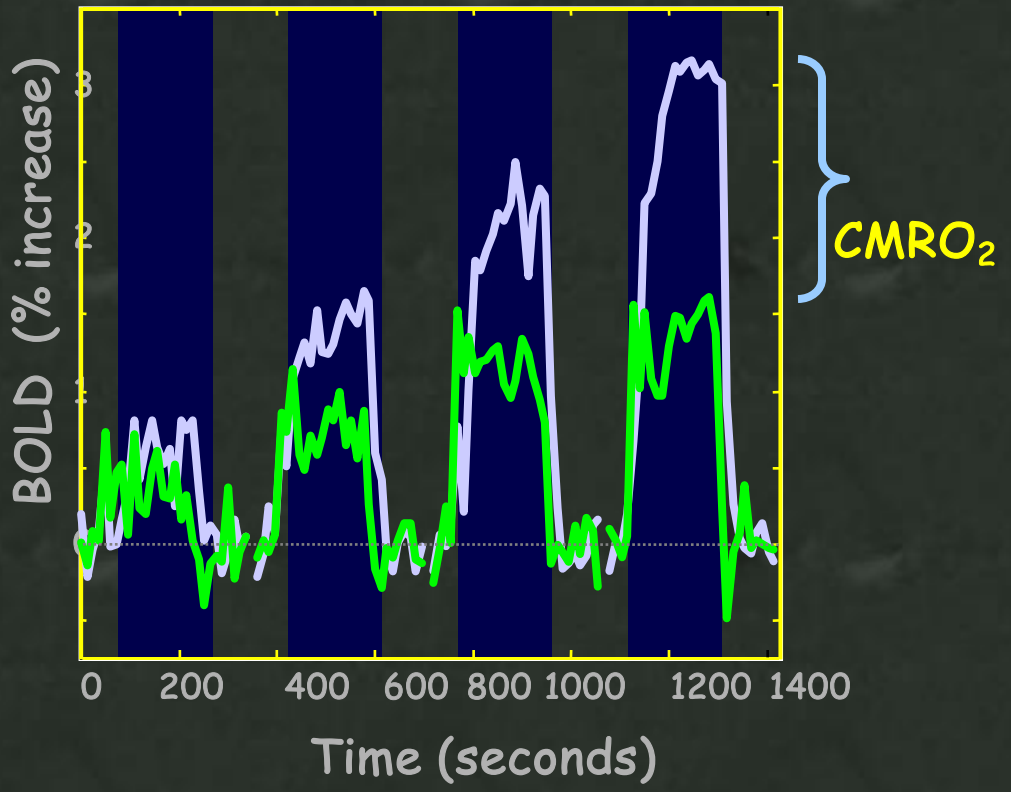
New Contrasts

$\Delta CMRO_2$

CBF



BOLD



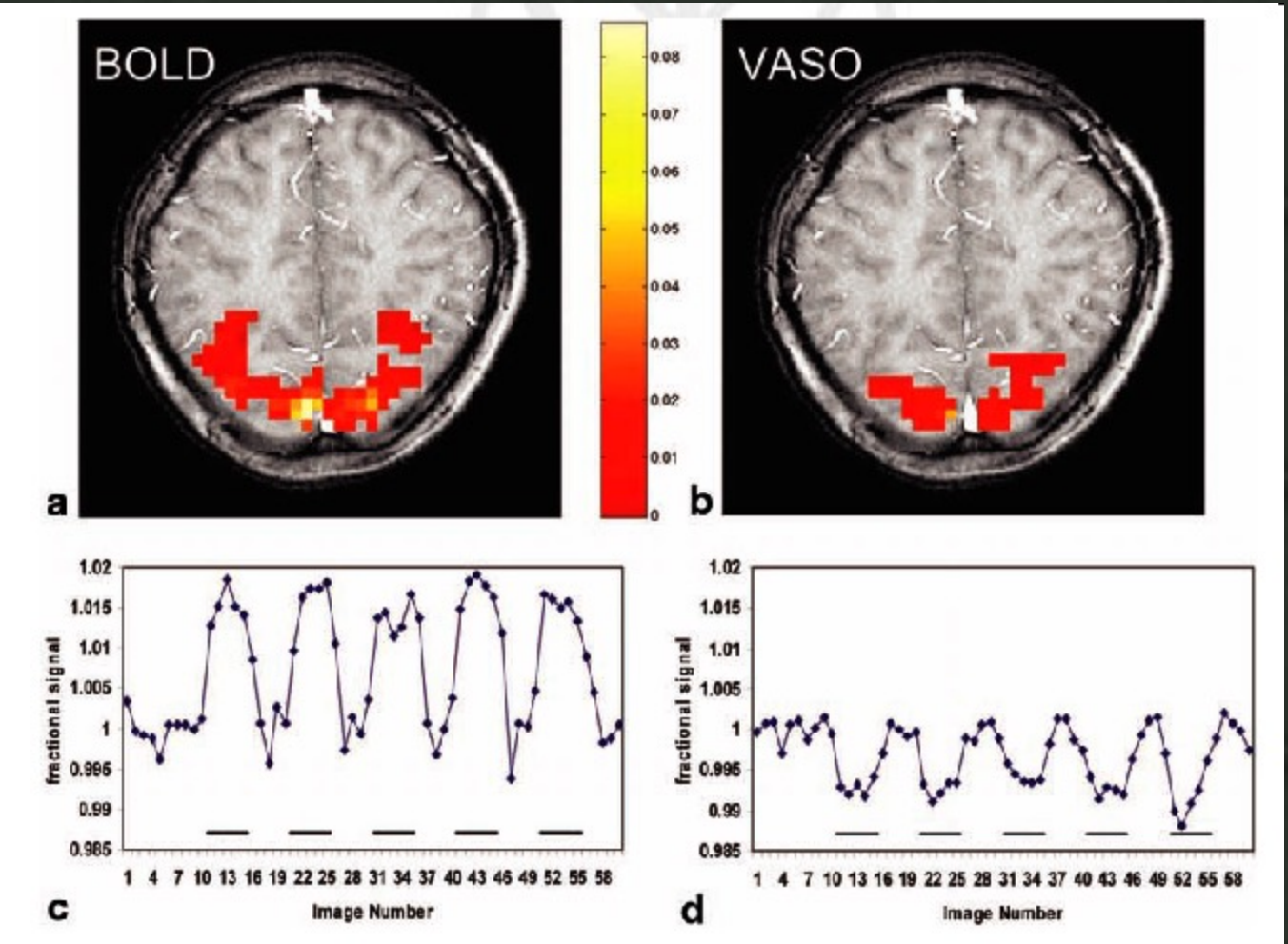
Simultaneous Perfusion and BOLD imaging during graded visual activation and hypercapnia

Hoge et al, PNAS 96: 9403-9408 (1999)

Methodology

New Contrasts

VASO



Lu et al, MRM 50 (2): 263-274 (2003)

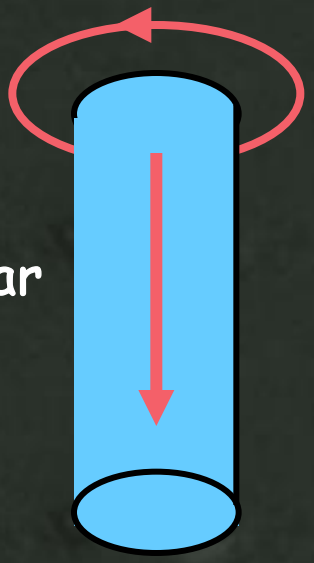
Methodology

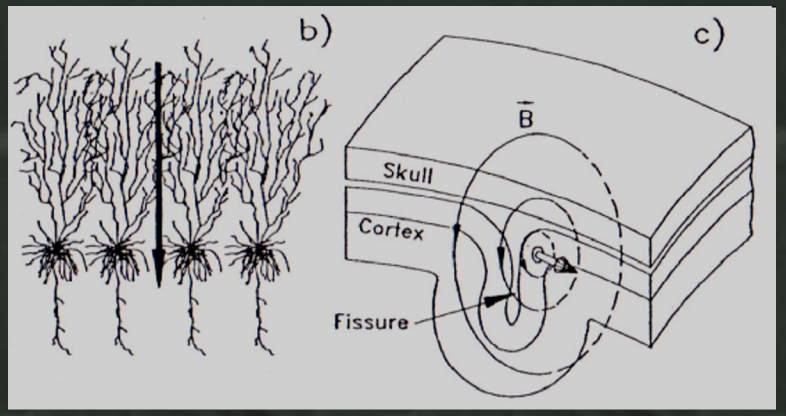
New Contrasts

Neuronal Currents

Magnetic Field

Intracellular Current





Surface Fields

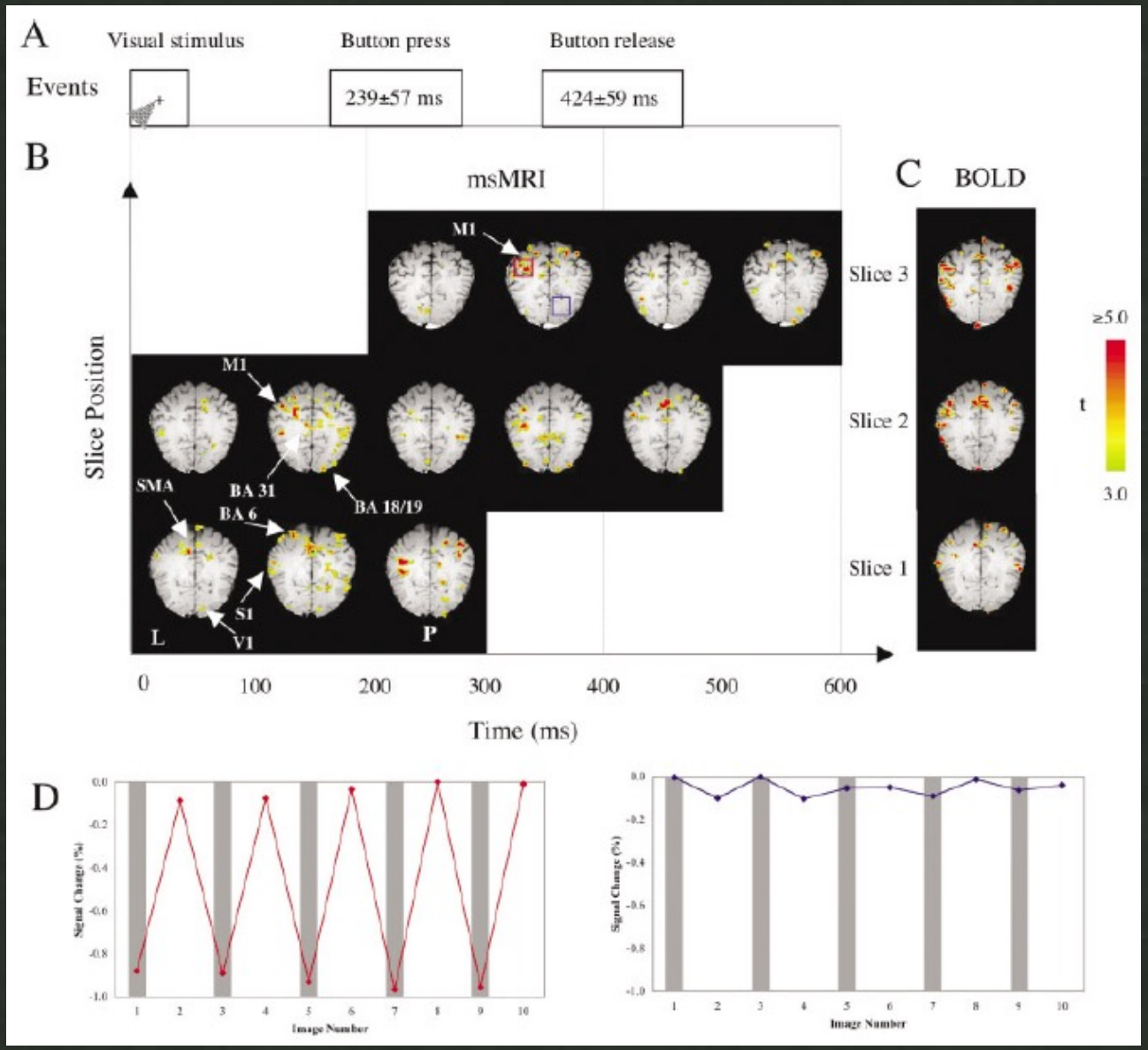
100 fT at on surface of skull

And 0.2 nT near source

Methodology

New Contrasts

Neuronal Currents



J. Xiong, P. T. Fox, J.-H. Gao, *Direct MRI Mapping of neuronal activity.* Human Brain Mapping, 20: 41-49, (2003)

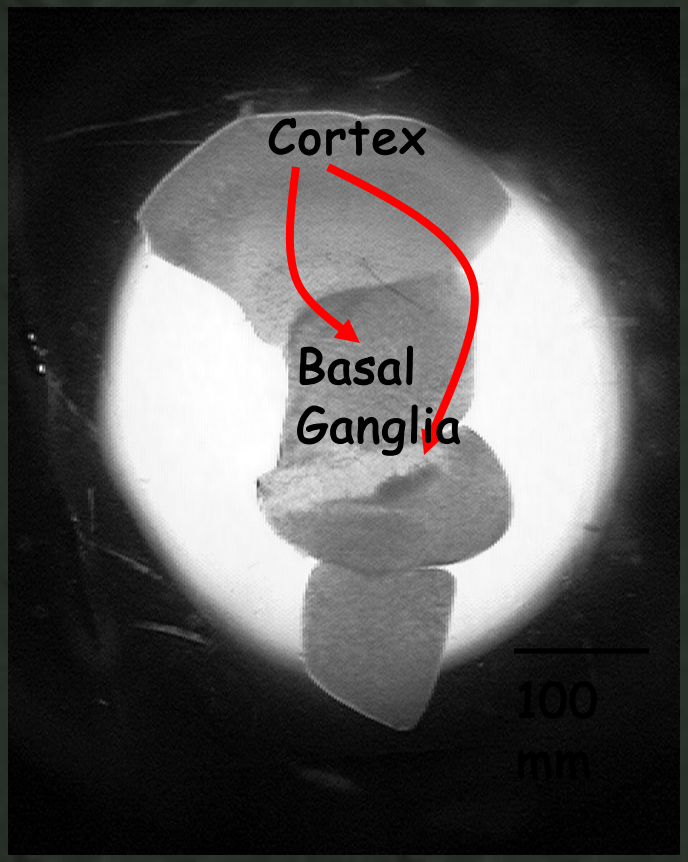
Methodology

New Contrasts

Neuronal Currents

In Vitro Results

Organotypic (*no blood supply or hemoglobin traces*) sections of newborn-rat somato-sensory Cortex, or somato-sensory Cortex & Basal Ganglia



- Size: in-plane:~1-2mm^2, thickness: 60-100μm
- Neuronal Population: 10,000-100,000

- Spontaneous synchronized activity < 2Hz
- Epileptiform activity
- Spontaneous beta freq. activity (20-30Hz)
- Network Activity Range: ~ 0.5-15μV

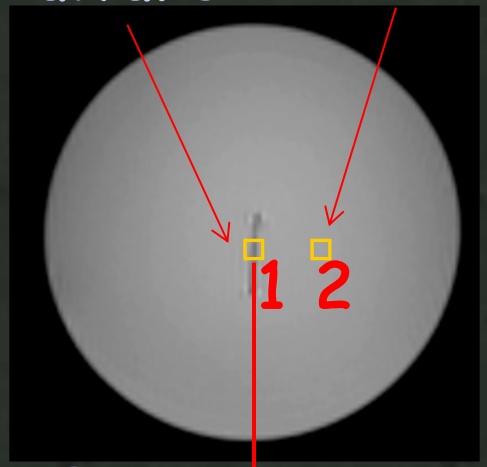
Plenz, D. et al. *Neurosci* 70(4): 861-924, 1996

Methodology

New Contrasts

Neuronal Currents

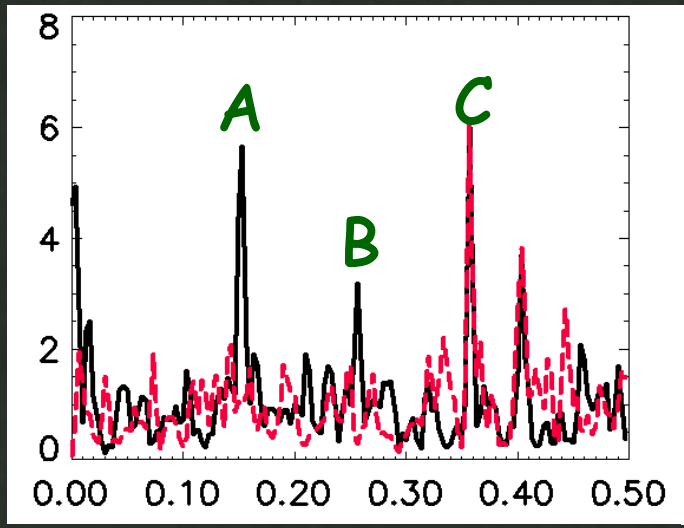
Culture ACSF



FSE image

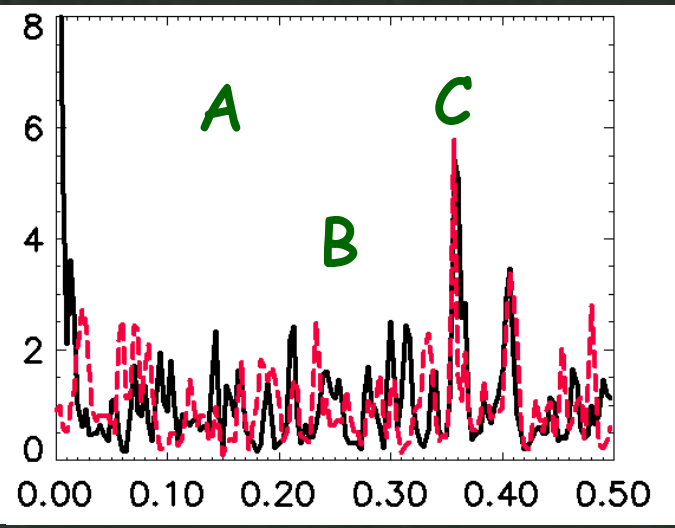
0.15Hz map

1: culture



Hz

2: ACSF



Hz

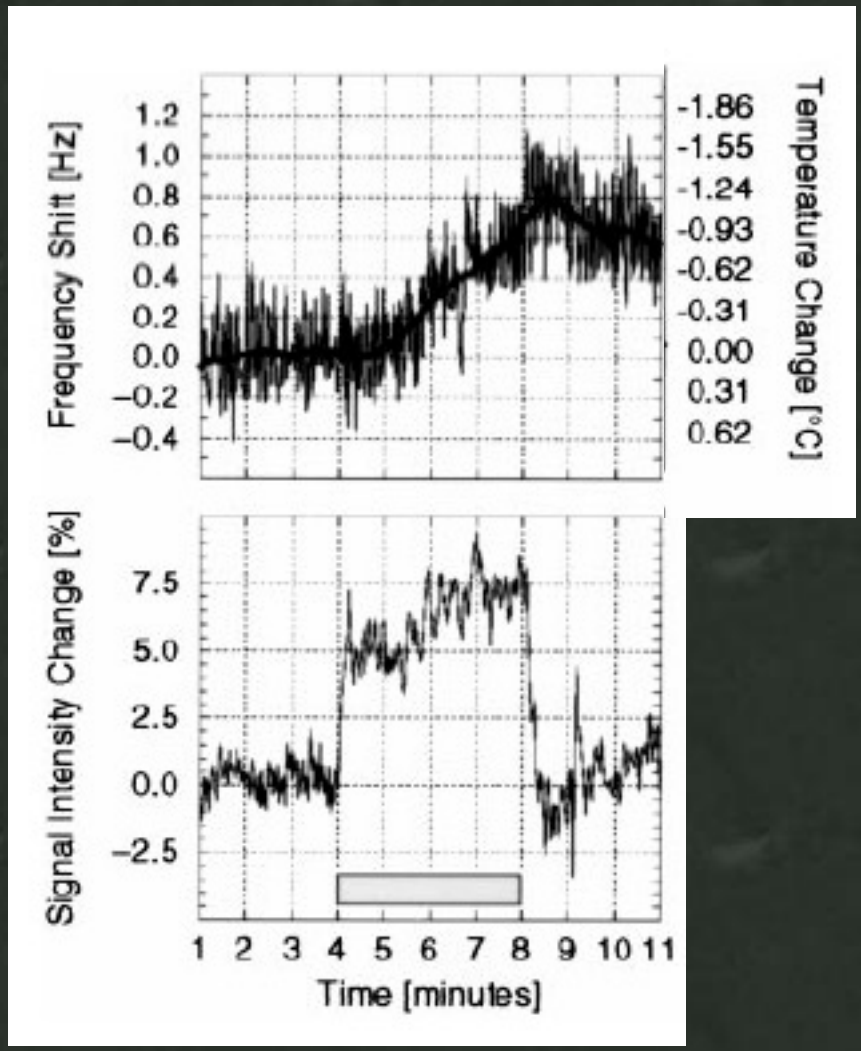
Active condition: black line
Inactive condition: red line

A: 0.15 Hz activity, on/off frequency
B: activity
C: scanner noise (cooling-pump)

Methodology

New Contrasts

Temperature

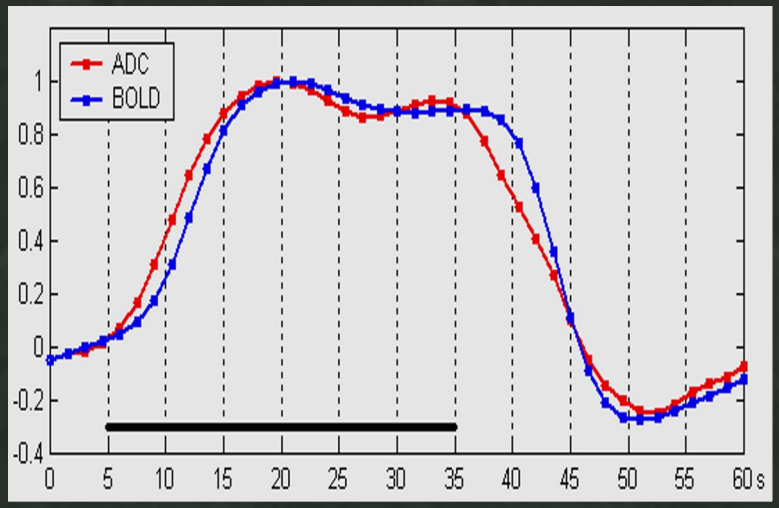


Yablonski, et al. PNAS 97: 7603-7608 (2000).

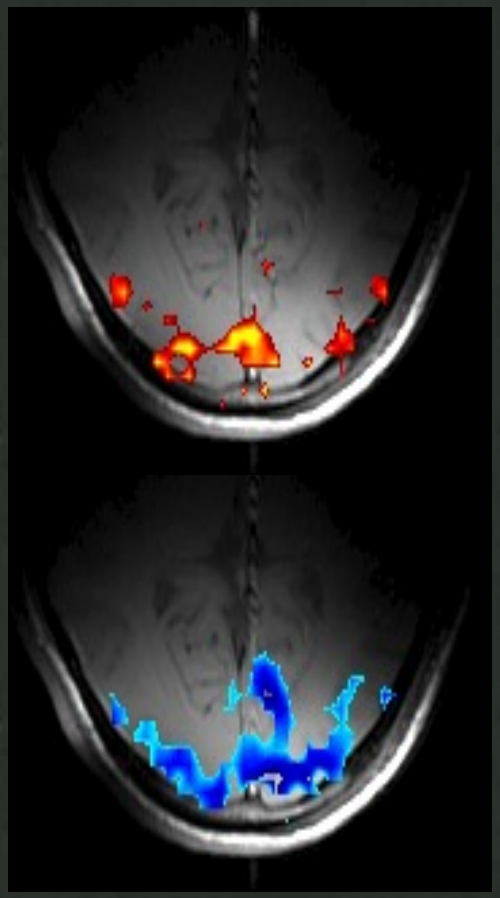
Methodology

New Contrasts

Diffusion Coefficient



ADC increase precedes BOLD increase



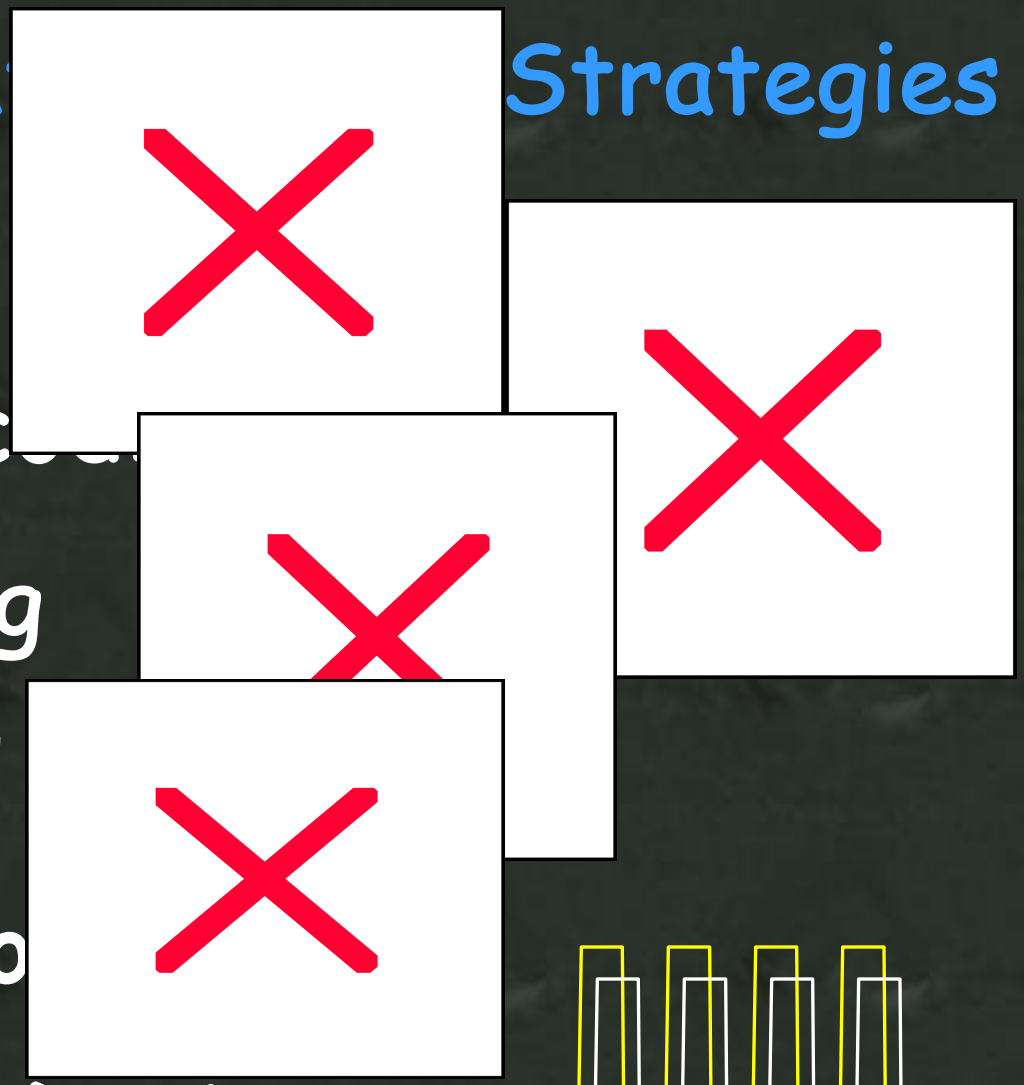
Gangstead and Song, MRM 48, 385-388, 2002

Song et al., NeuroImage, 20, 955-961, 2003.

Methodology

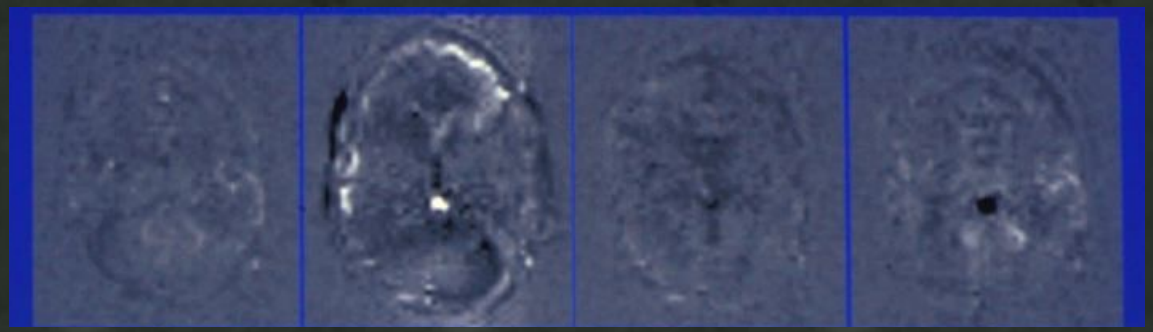
Neuronal Activa Strategies

1. Block Design
2. Frequency Enc
3. Phase Encoding
4. Event-Related
5. Orthogonal Blo
6. Free Behavior Design.

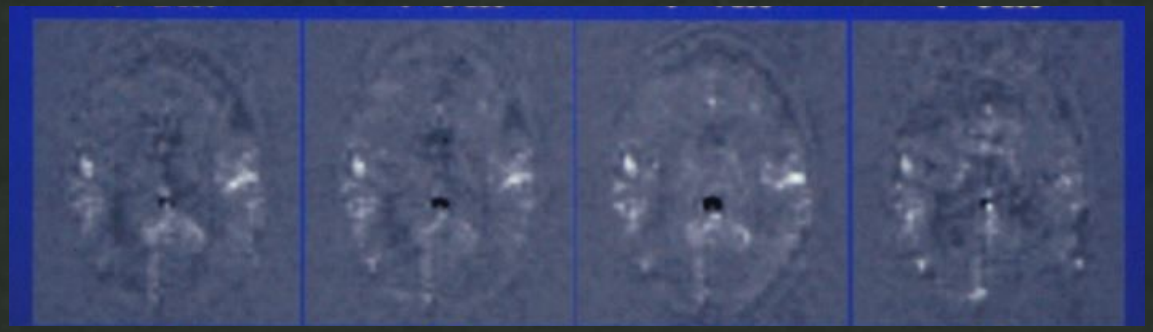


Methodology

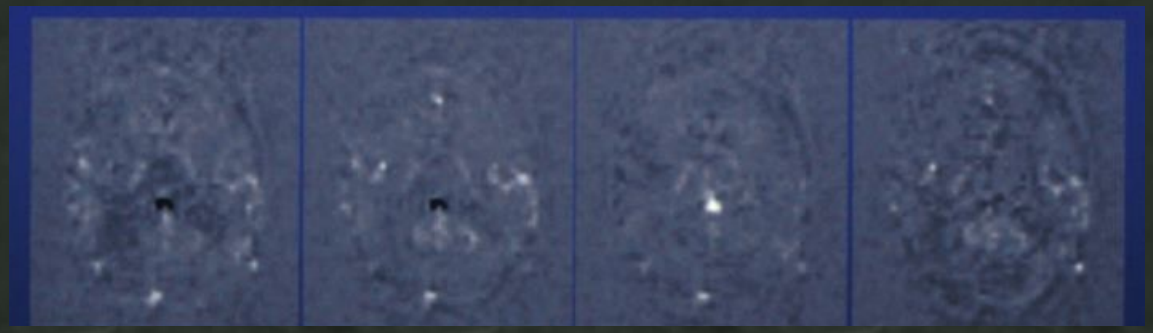
Overt Word Production



2 3 4 5

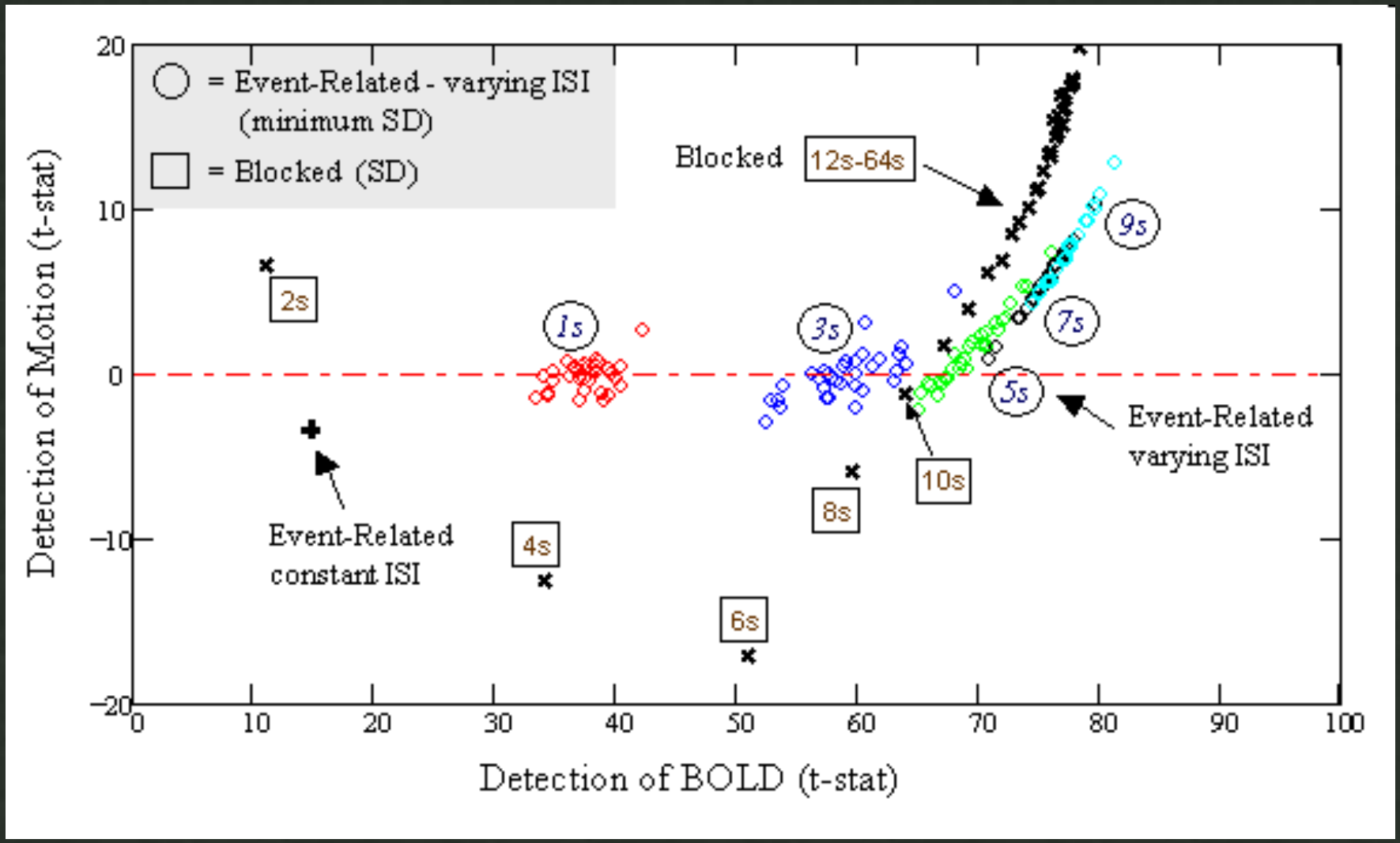


6 7 8 9



10 11 12 13

Methodology

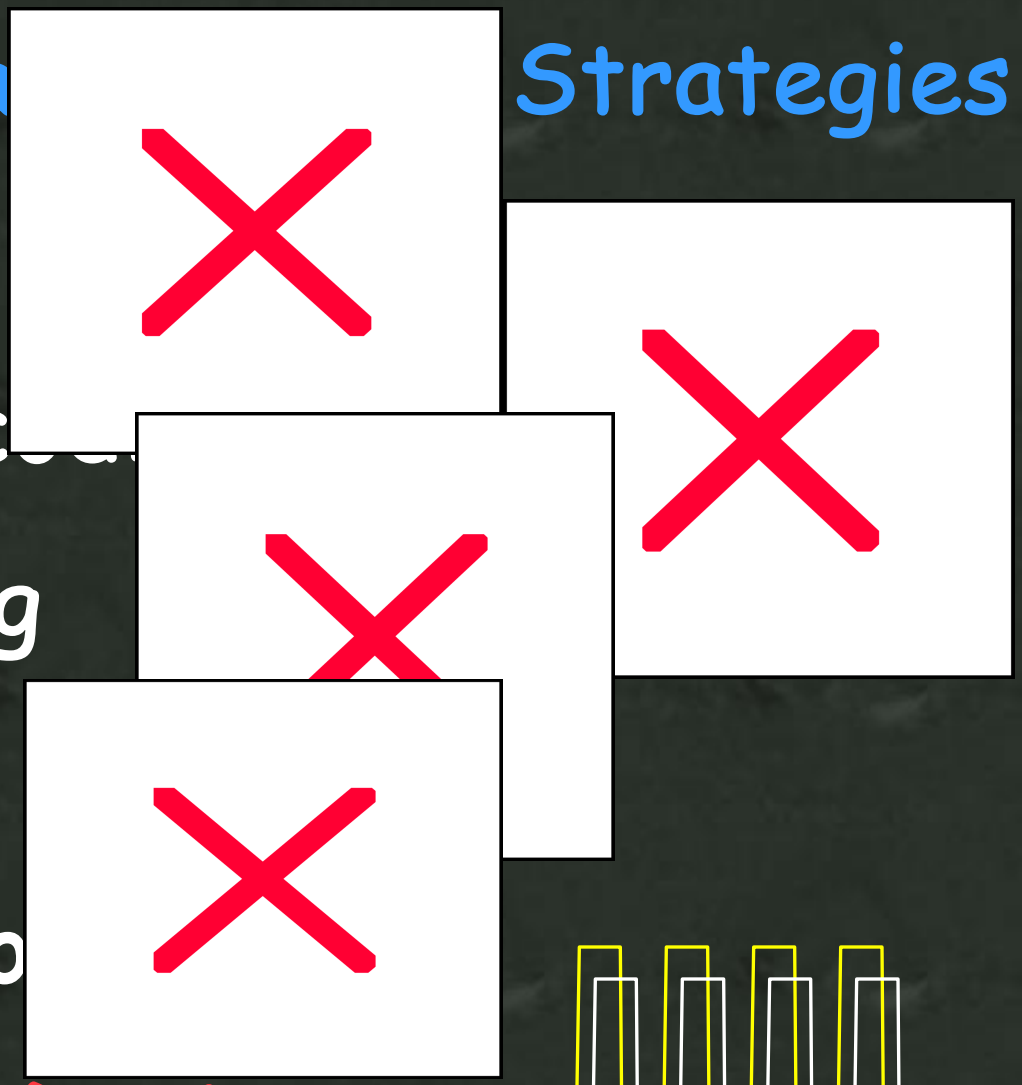


R.M. Birn, R. W. Cox, P. A. Bandettini. *NeuroImage,* **23 1046-1058 (2004)**

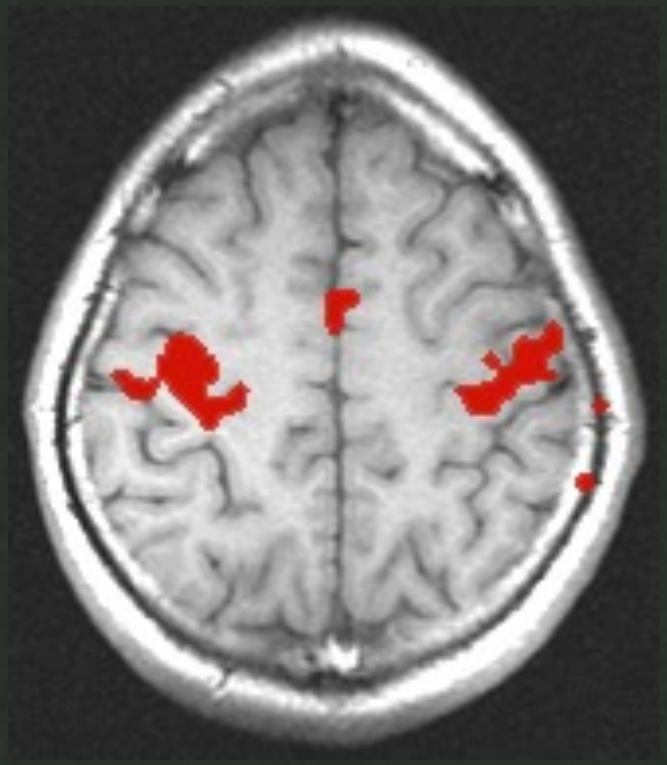
Methodology

Neuronal Activa Strategies

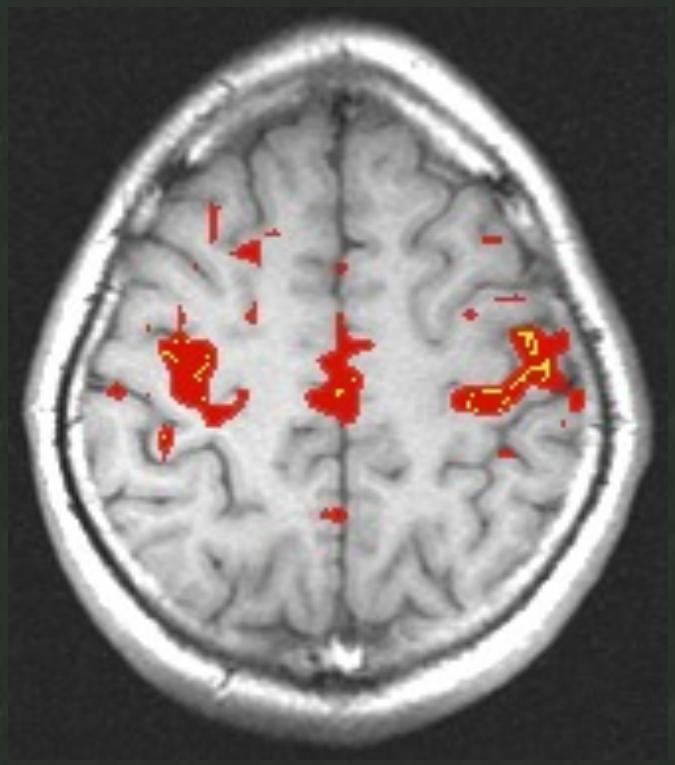
1. Block Design
2. Frequency Enc
3. Phase Encoding
4. Event-Related
5. Orthogonal Blo
6. Free Behavior Design.



Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

B. Biswal *et al.*, MRM, 34:537 (1995)

Methodology

NAIS

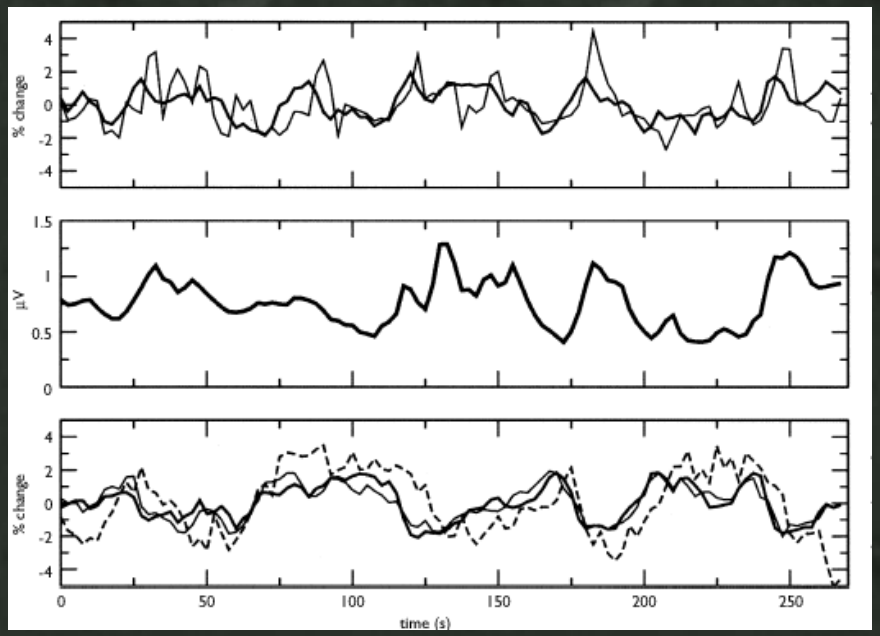
Free Behavior

BOLD correlated with 10 Hz power during "Rest"

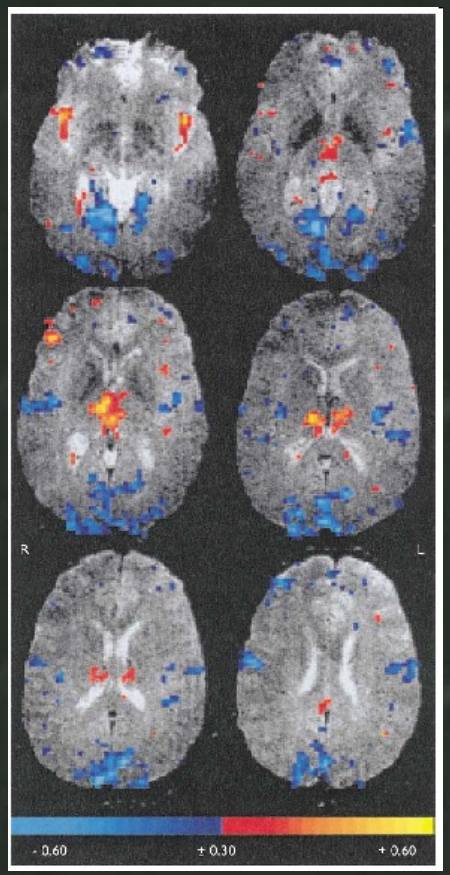
Positive

10 Hz power

Negative



Goldman, et al (2002), Neuroreport

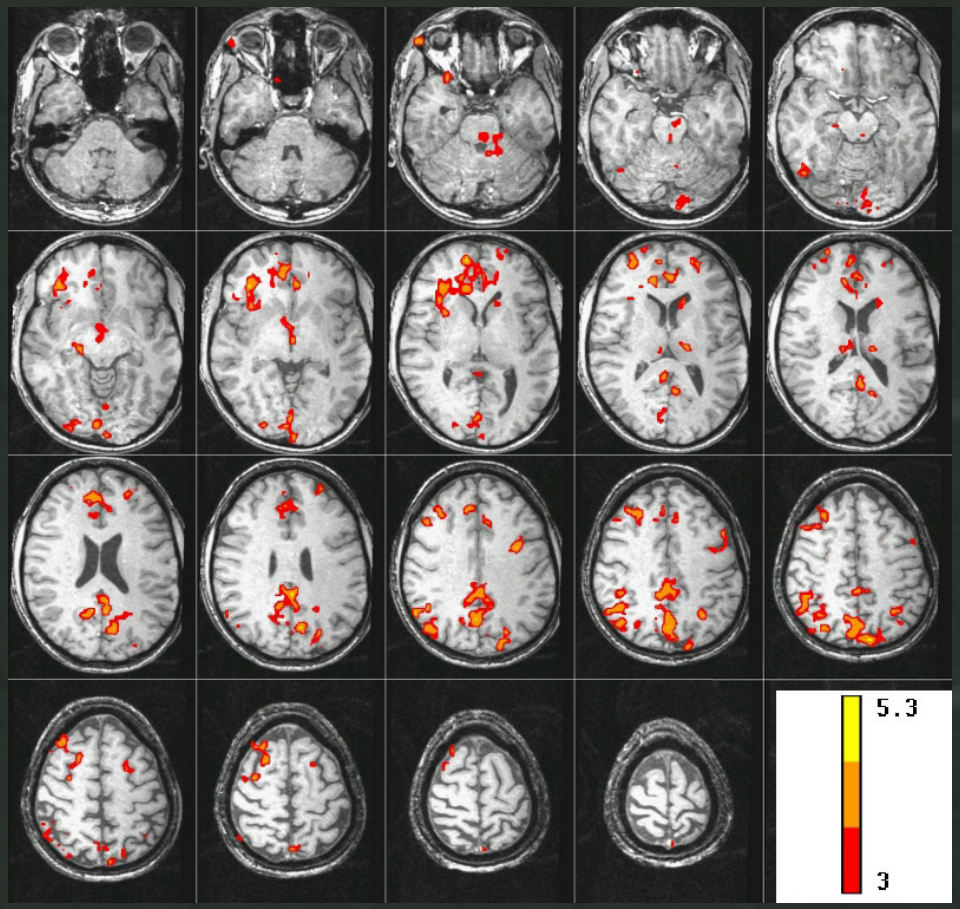


Methodology

NAIS

Free Behavior

BOLD correlated with SCR during "Rest"



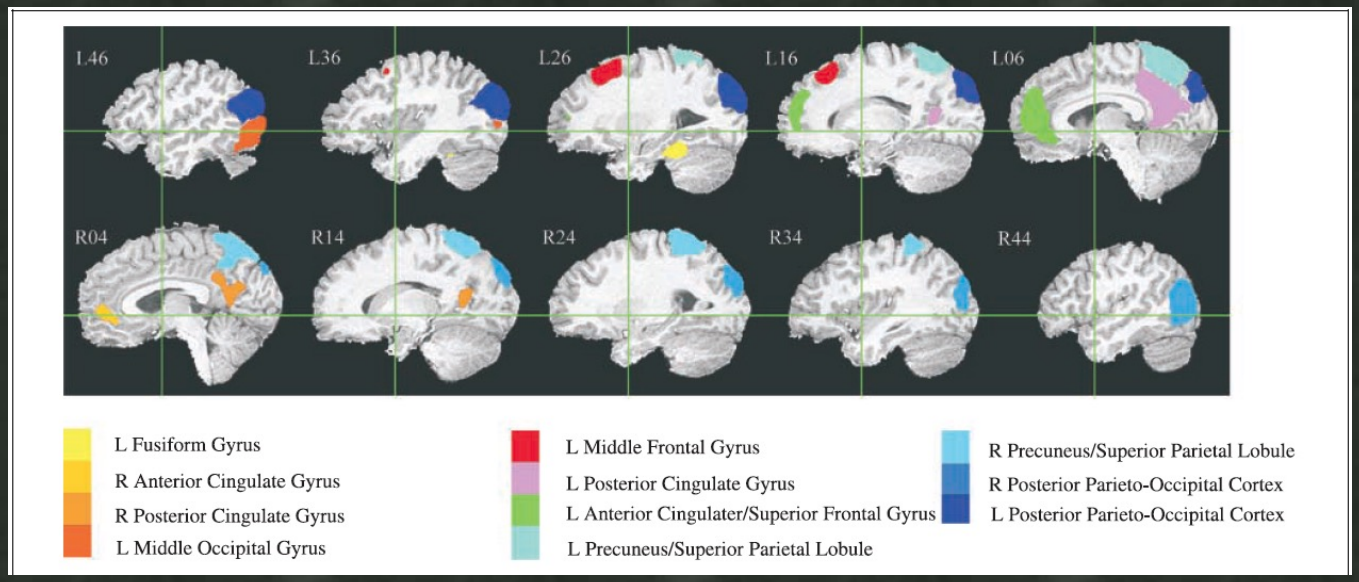
J. C. Patterson II, L. G. Ungerleider, and P. A Bandettini, *NeuroImage* **17**: *1787-1806, (2002).*

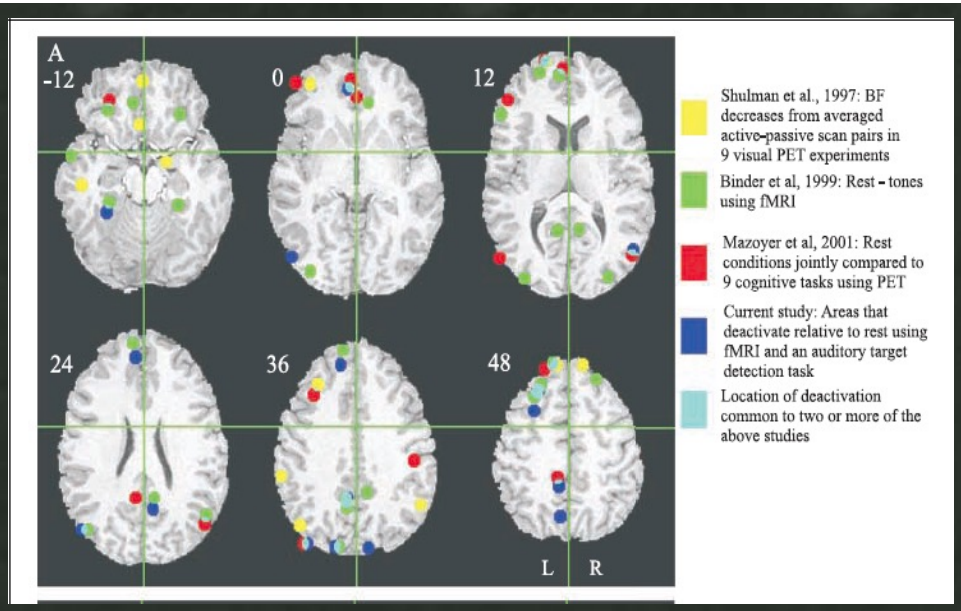
Methodology

NAIS

Free Behavior

Regions showing decreases during cognitive tasks



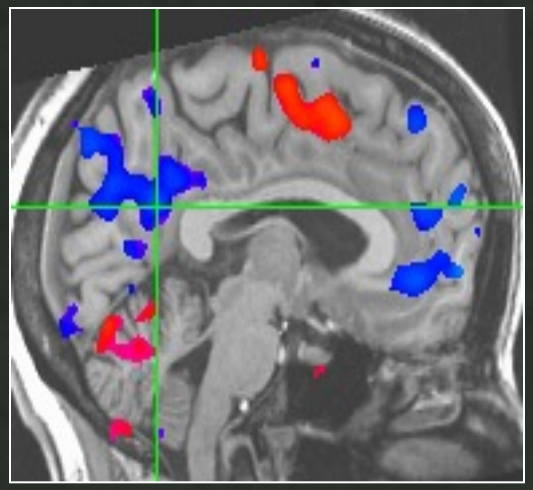


McKiernan, et al (2003), Journ. of Cog. Neurosci. 15 (3), 394-408

Methodology

NAIS

Free Behavior



Lexical Task

ROI

Functional Connectivity

J. Diamond, M. Smith, R. Birn

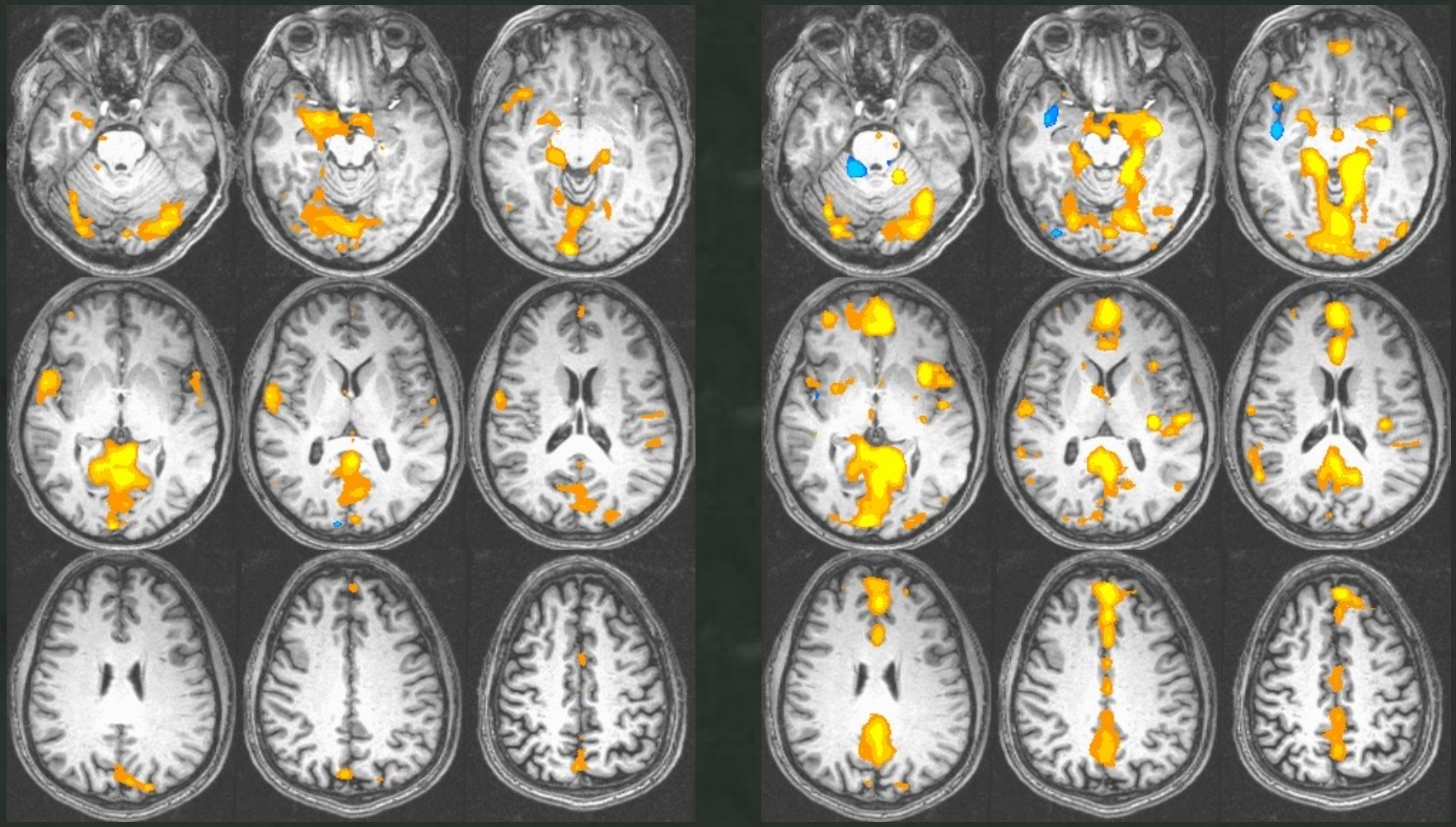
Methodology

NAIS

Free Behavior

Right

Left



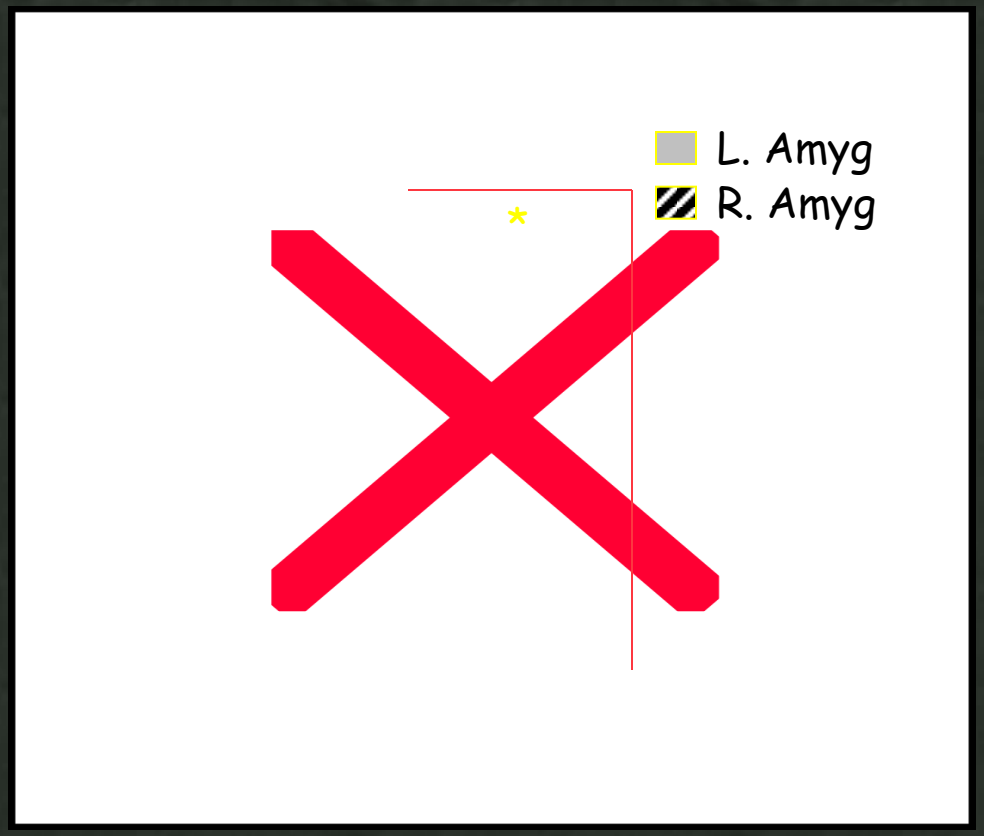
Brain regions showing strong correlation with left and right amygdala activity.

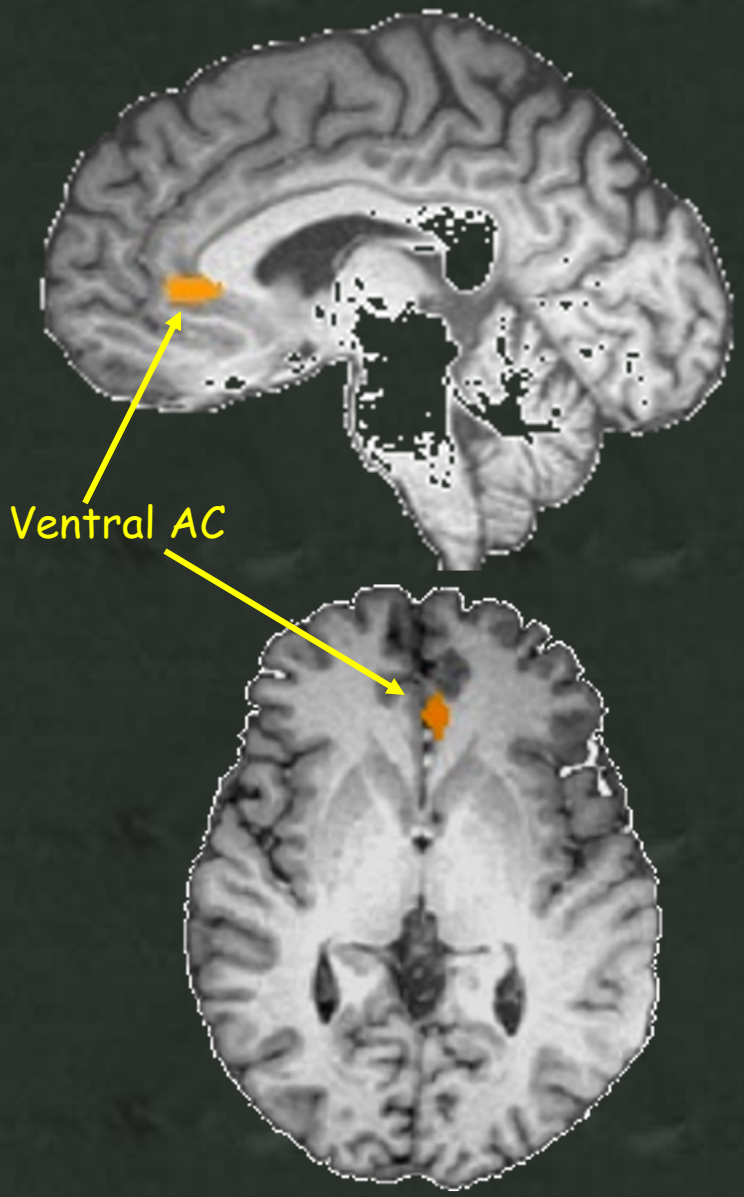
D. Knight, H. Nguyen

Methodology

NAIS

Free Behavior





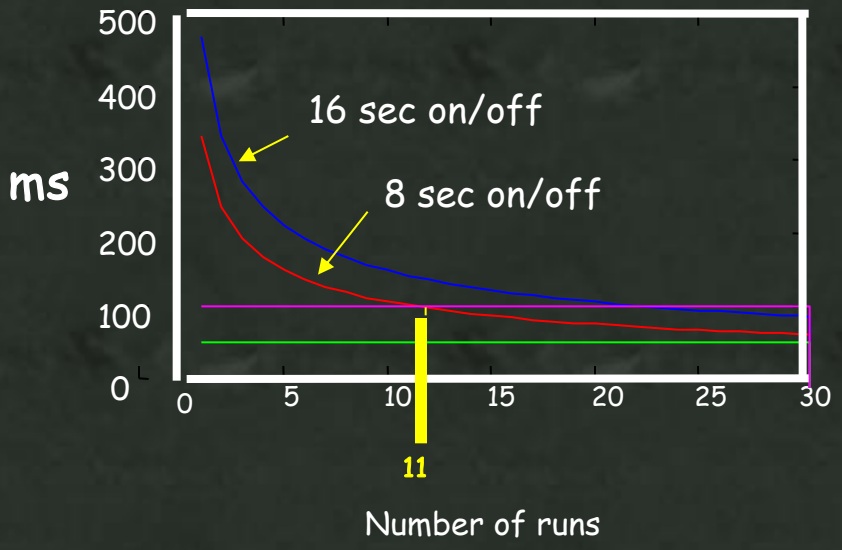
Fit coefficient comparing similarity of ventral AC activity with left and right amygdala activity. Activity within the ventral AC was more strongly associated with left than right amygdala activity.

D. Knight, H. Nguyen

Methodology

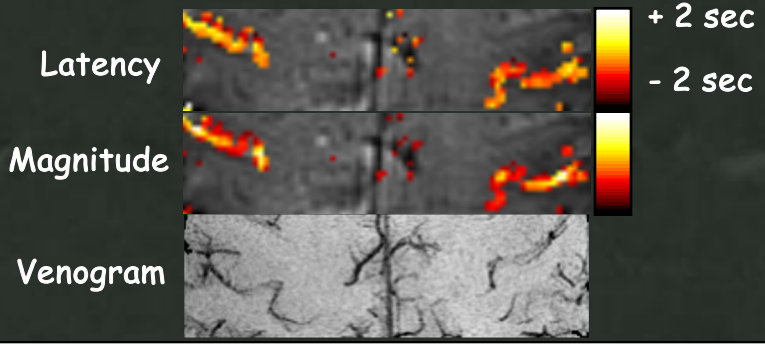
Temporal Resolution

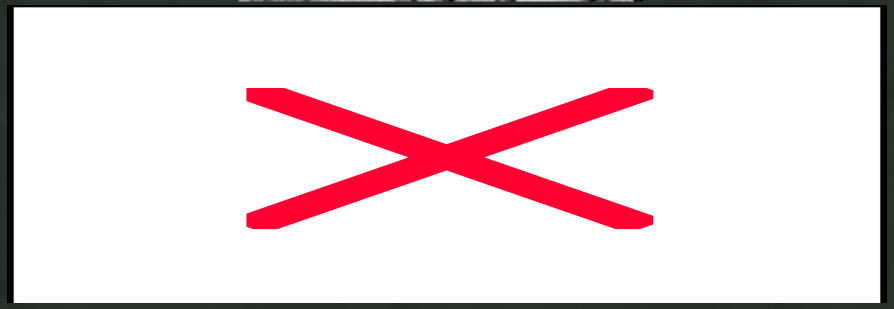
In an ideal world… no latency variation



R. Birn

Latency Variation…





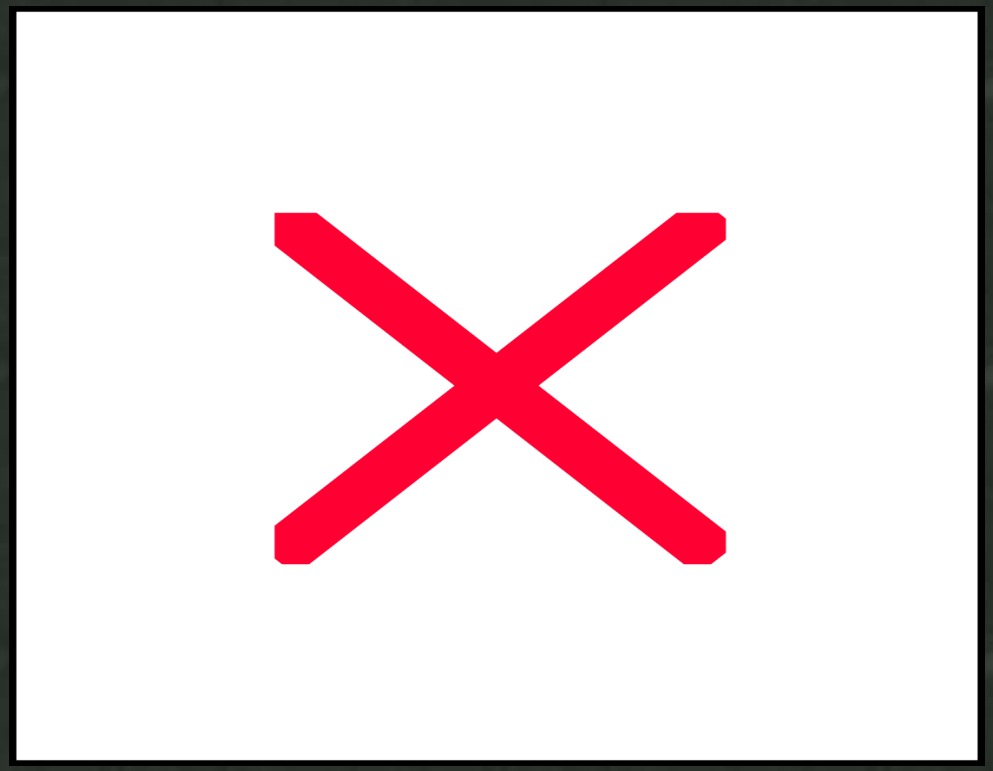
P. A. Bandettini, (1999) "Functional MRI" 205-220.

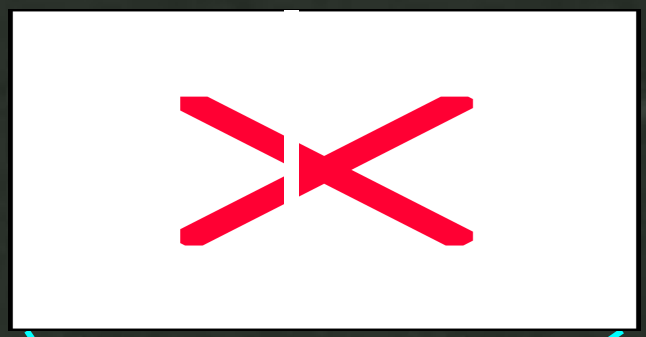
Methodology

Temporal Resolution

Word vs. Non-word

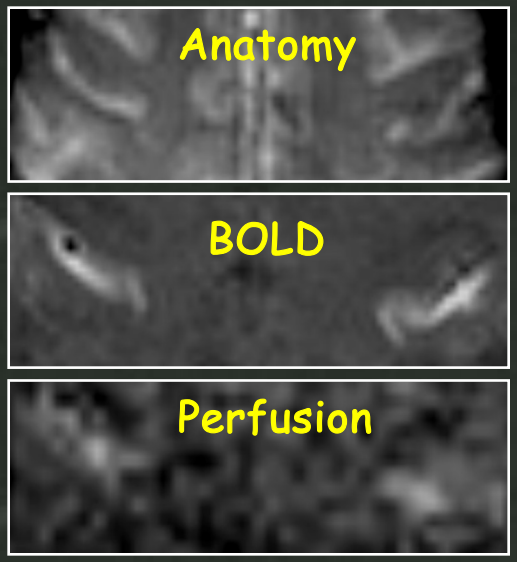
0°, 60°, 120° Rotation





Bellgowan, et al (2003), PNAS 100, 15820–15283

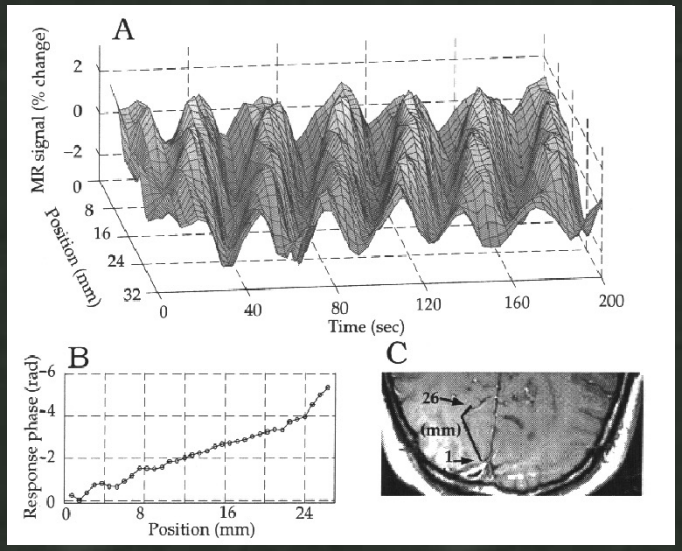
Methodology



P. A. Bandettini, (1999) "Functional MRI" 205-220.

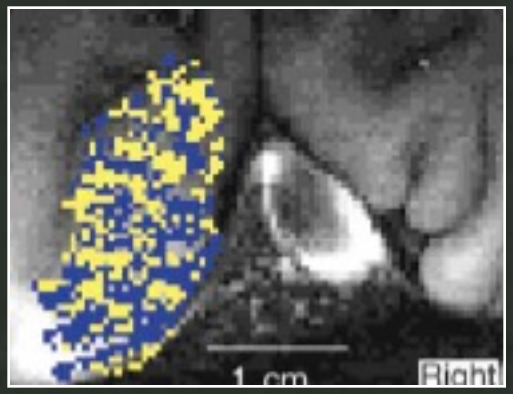
Spatial Resolution

PSF FWHM = 3.5mm



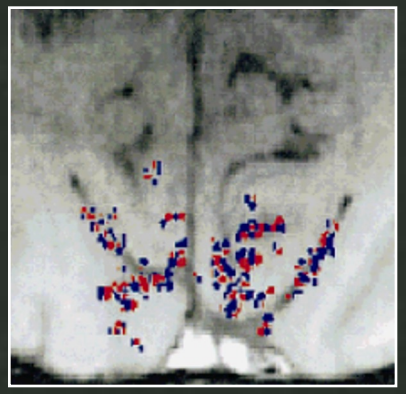
S.A. Engel, et al. Investigative Ophthalmology & Visual Science 35 (1994) 1977-1977.

0.47 x 0.47 in plane resolution



Cheng, et al. (2001) Neuron,32:359-374

0.54 x 0.54 in plane resolution



Menon et al, (1999) MRM 41 (2): 230-235

Multi-shot with navigator pulse

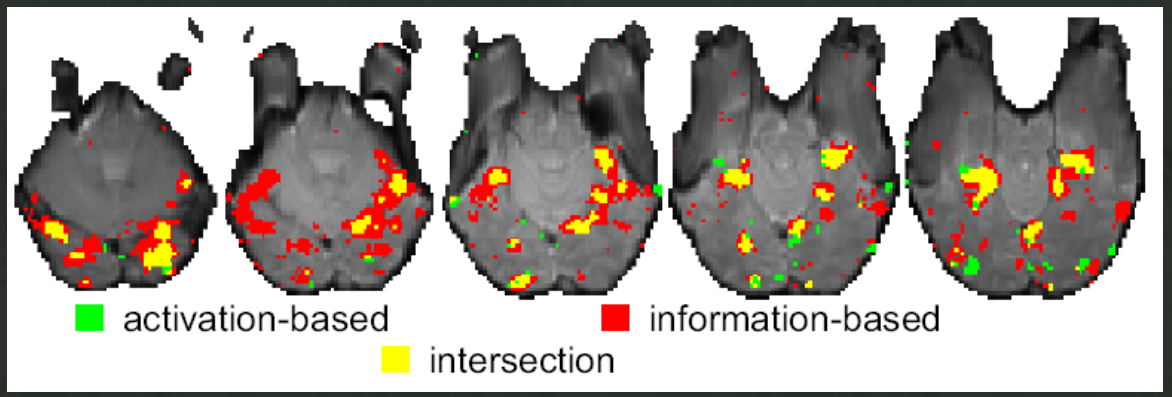
Methodology

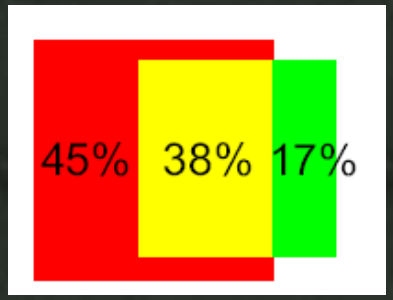
Processing Methods

Activation-based mapping: data smoothing
(classical approach)

Information-based mapping: local multivariate analysis

volume scanned with MANCOVA searchlight→



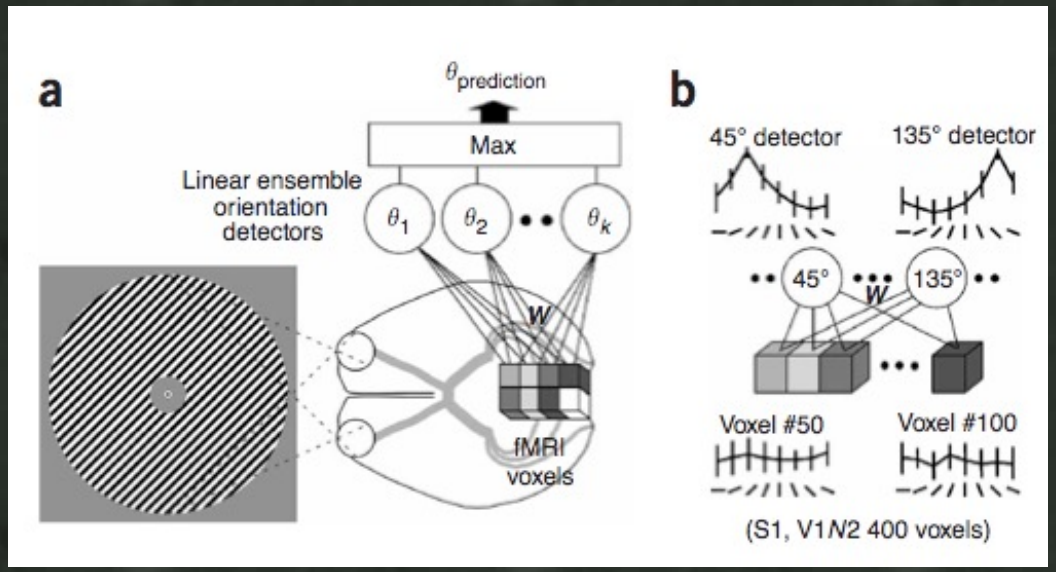


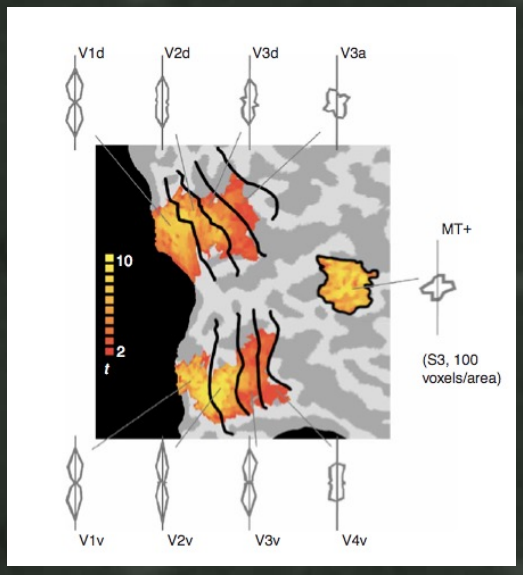
voxel sets

N. Kriegeskorte

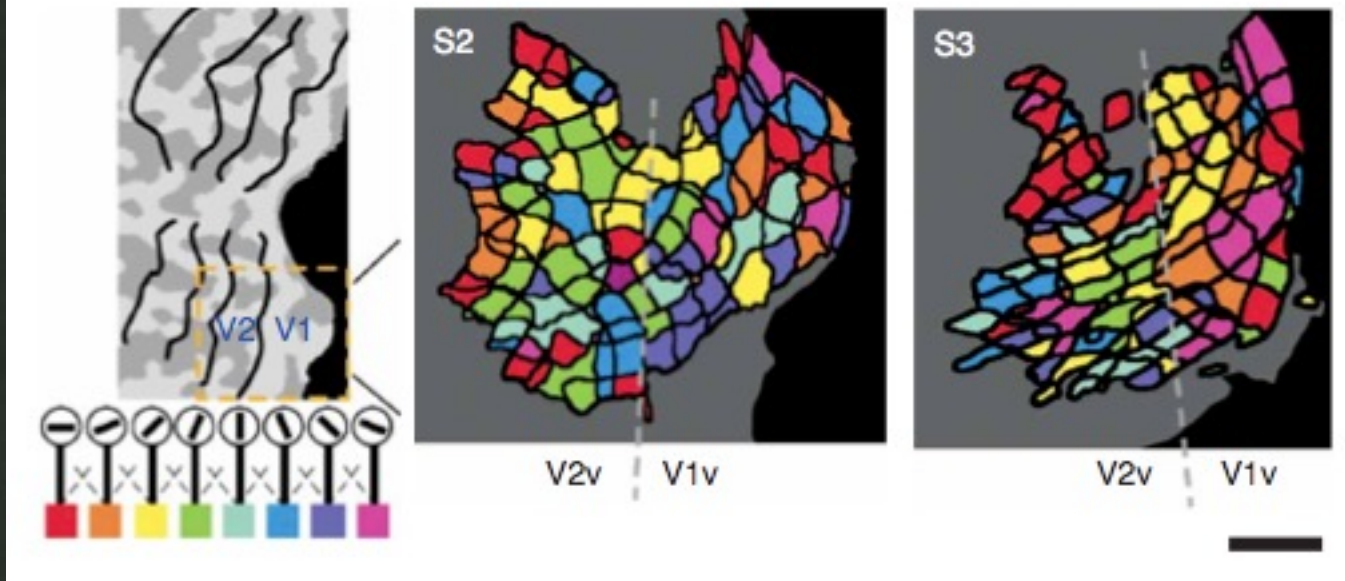
Methodology

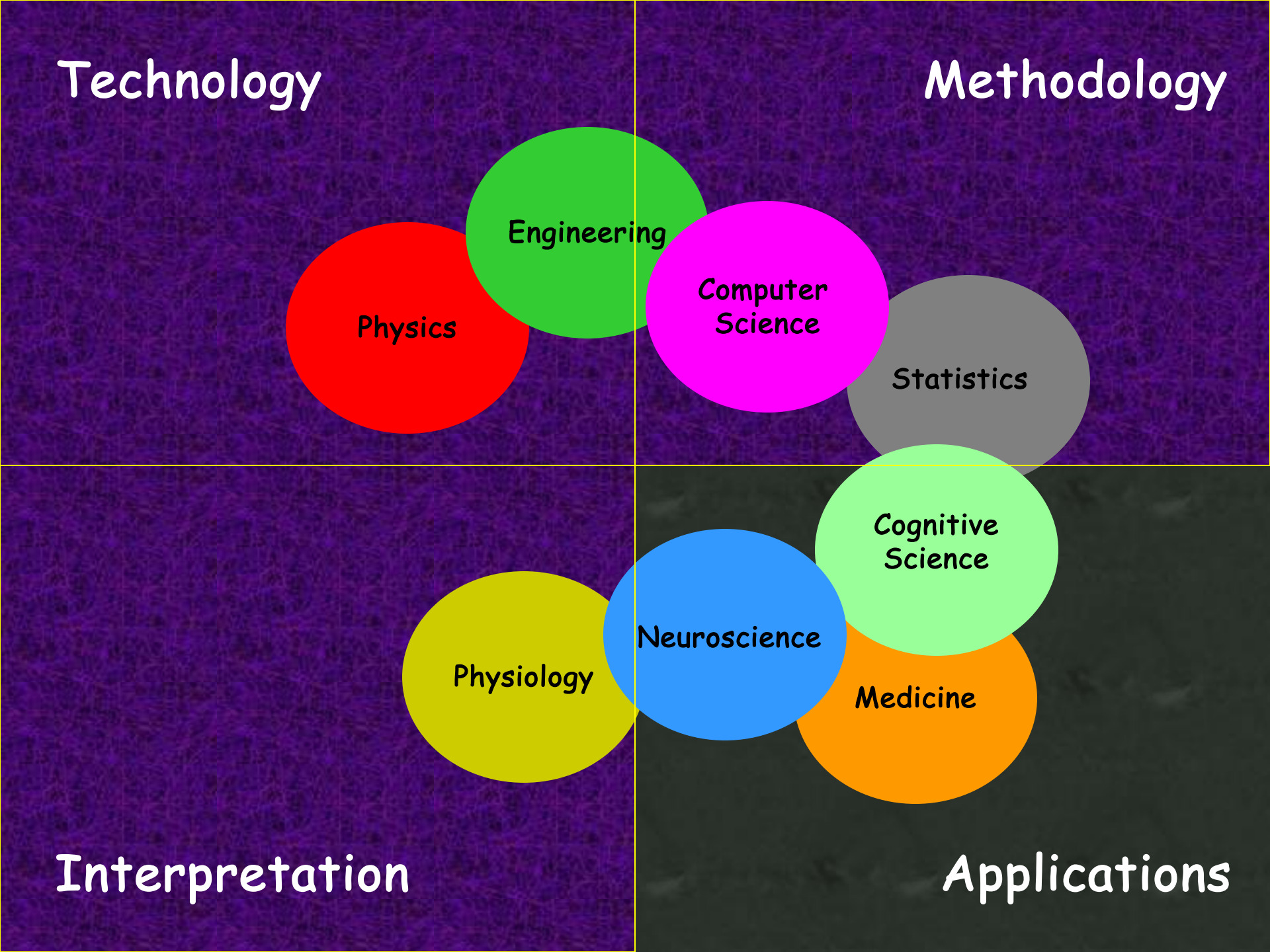
Processing Methods





Y. Kamatani and F. Tong, Nature Neuroscience, 8, 679-685.




Technology
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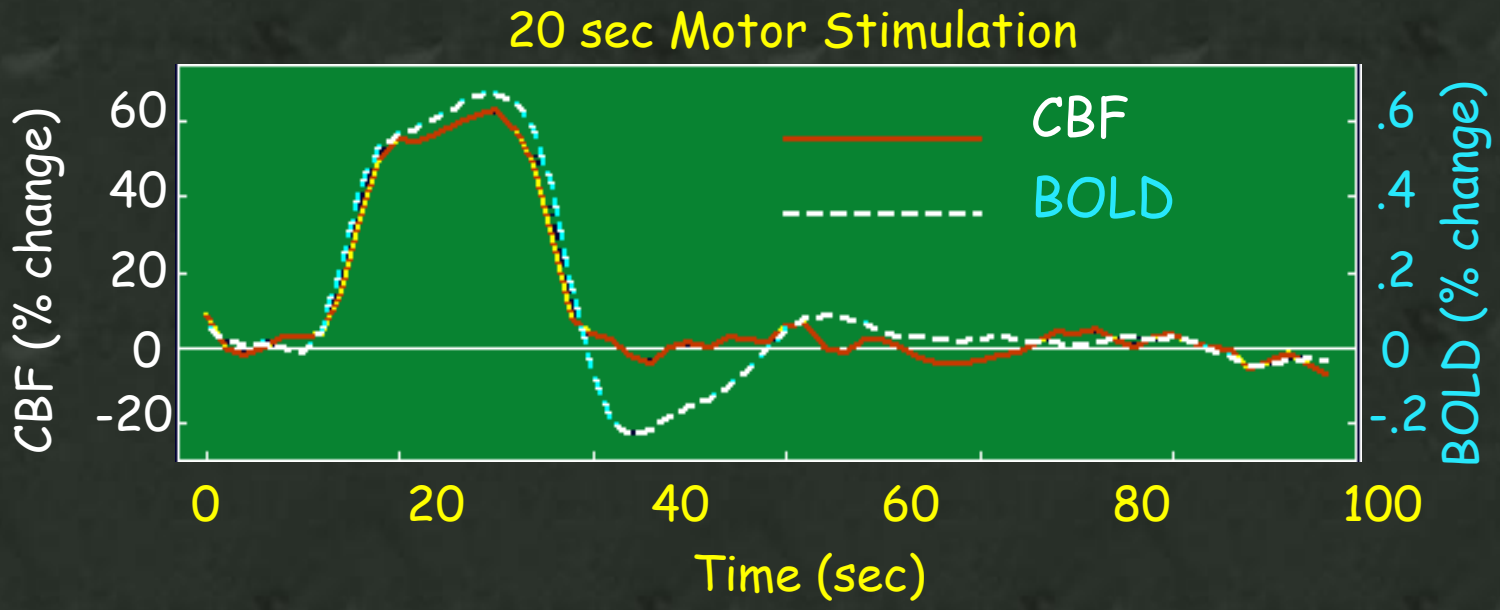
Interpretation
Applications

Interpretation

- Post Undershoot
- Linearity
- Local Field Potentials vs Spiking
- Inhibition and Decreases

BOLD post-stimulus undershoot



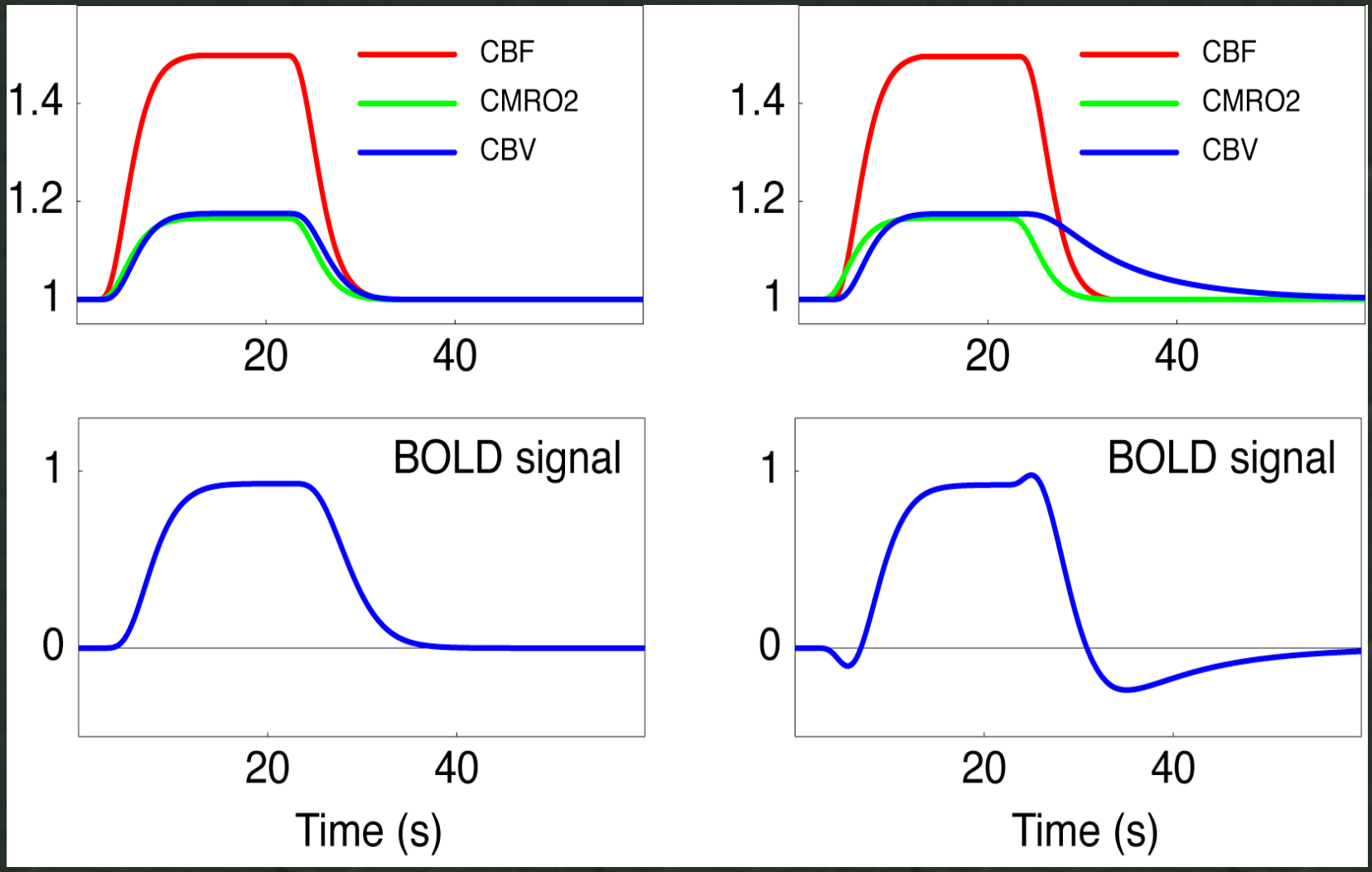
A BOLD undershoot without a CBF undershoot could be due to a slow return to baseline of either CBV or $CMRO_2$

Courtesy Rick Buxton

Interpretation

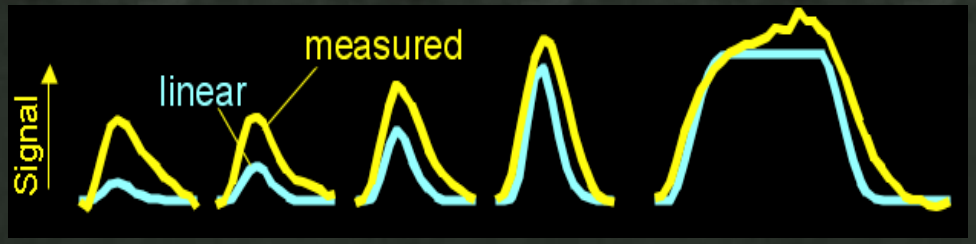
Post Undershoot

BOLD Signal Dynamics

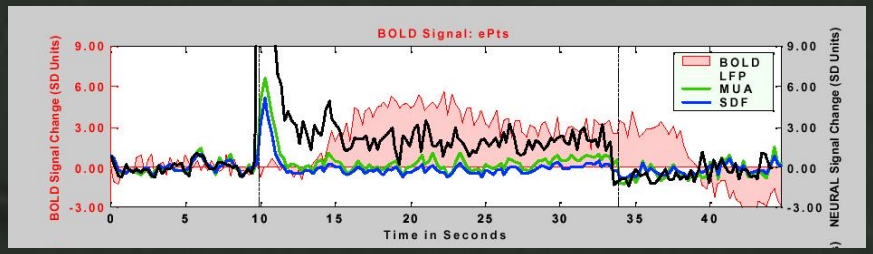


Courtesy Rick Buxton

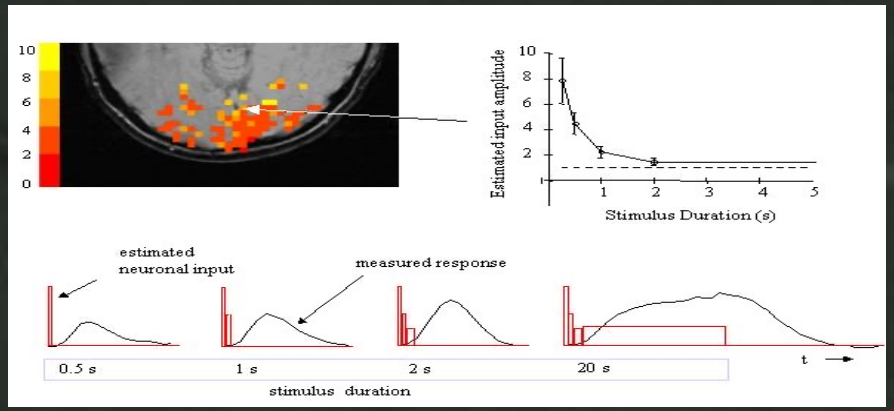
Increases: linearity



R. M. Birn, (2001) NeuroImage, 14: 817-826.



Logothetis et al. (2001) Nature, 412, 150-157.

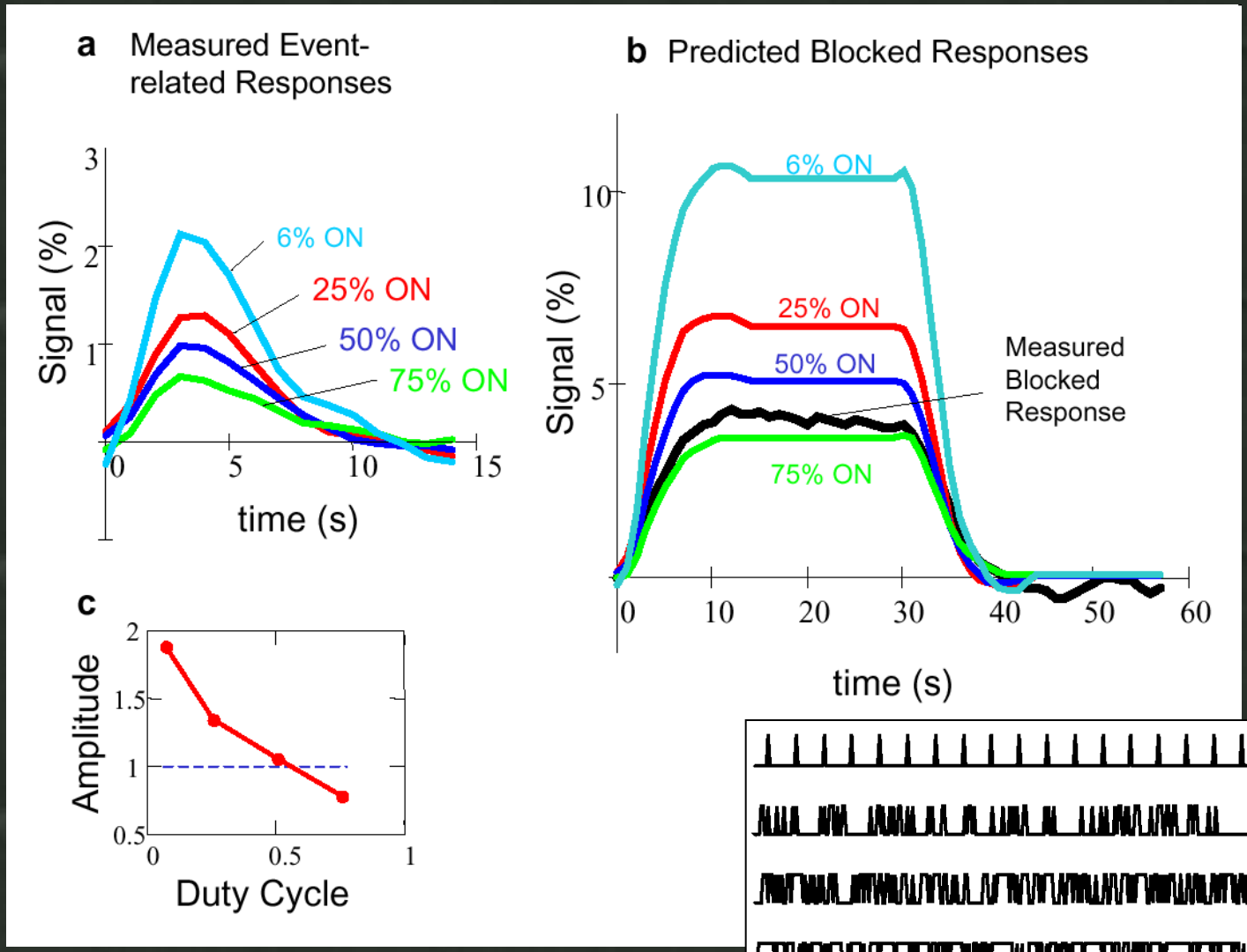


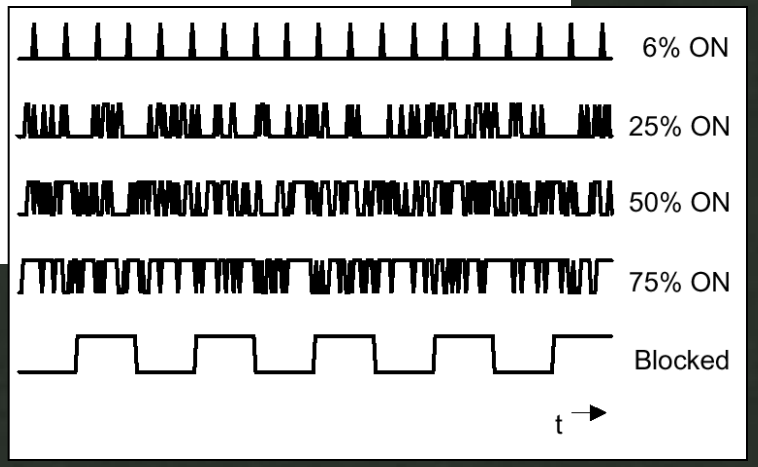
P. A. Bandettini et al, (2001) Nature Neuroscience, 4: 864-866.

Interpretation

Increases: duty cycle

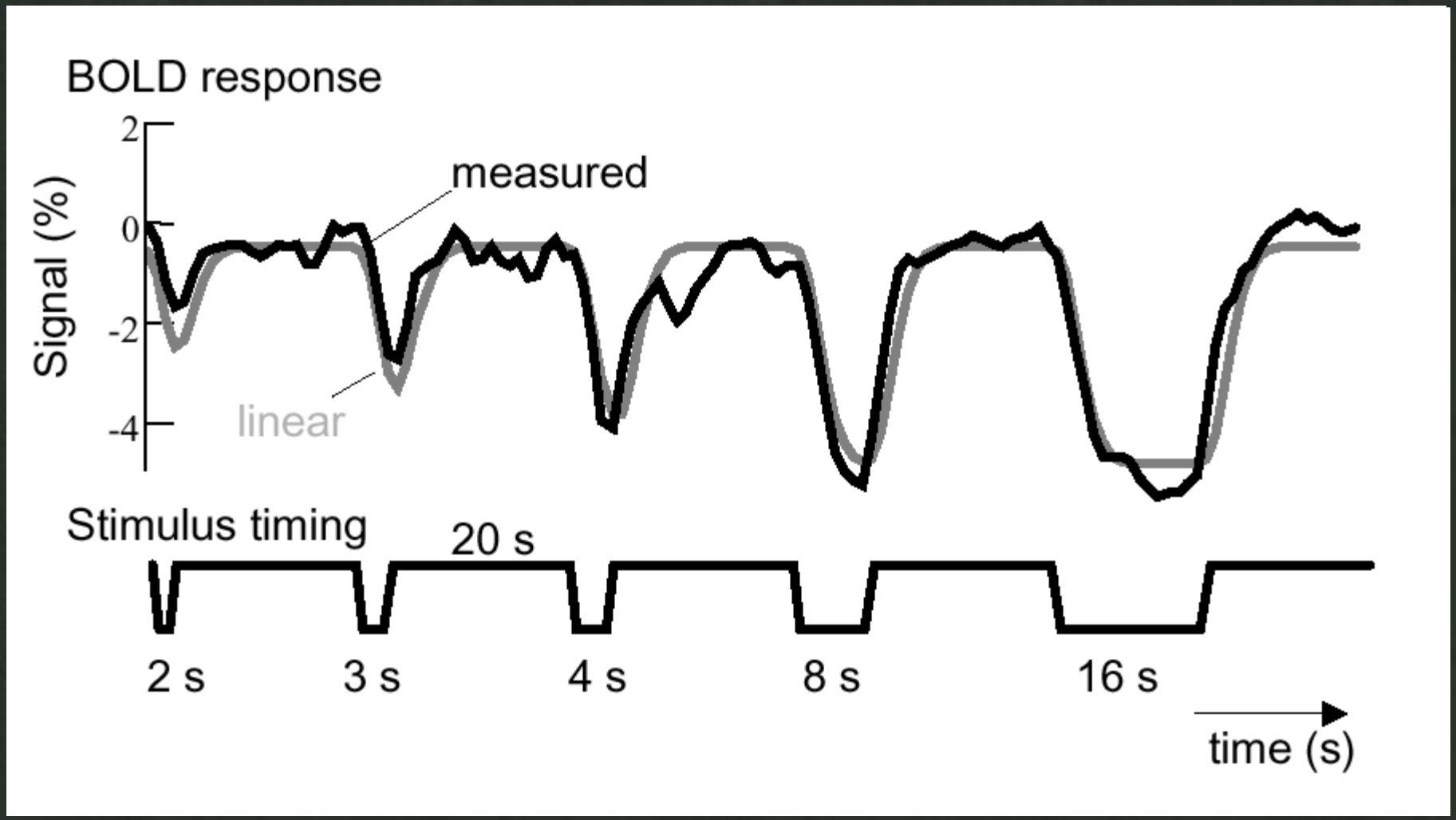
Linearity





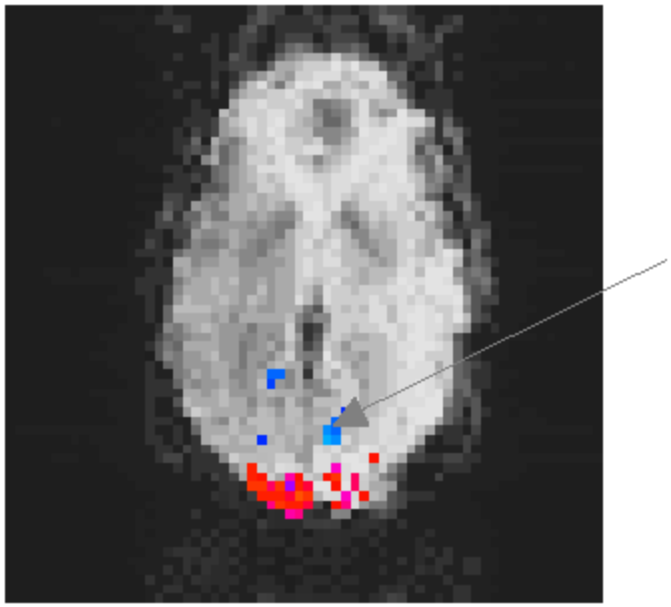
R.M. Birn, P. A. Bandettini. *NeuroImage, (in press)*

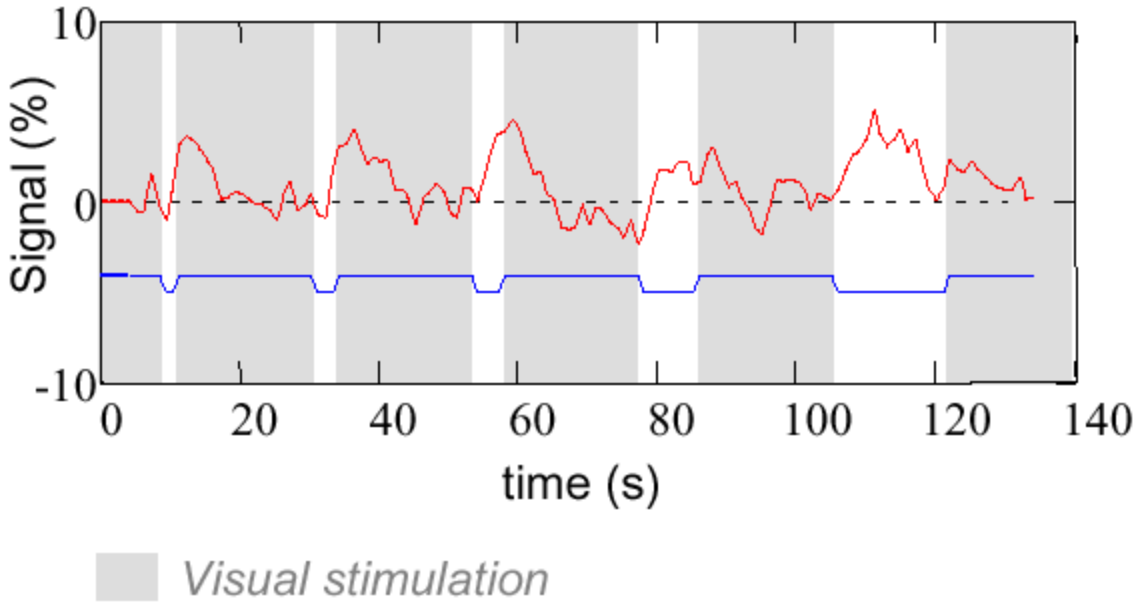
Decreases: linearity



R.M. Birn, P. A. Bandettini. *NeuroImage, (in press)*

We also see increases during stimulus cessation...



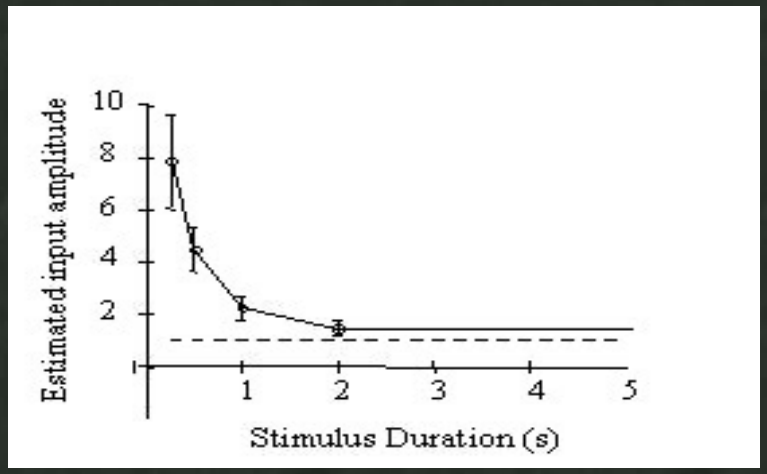


R.M. Birn, P. A. Bandettini. *NeuroImage, (in press)*

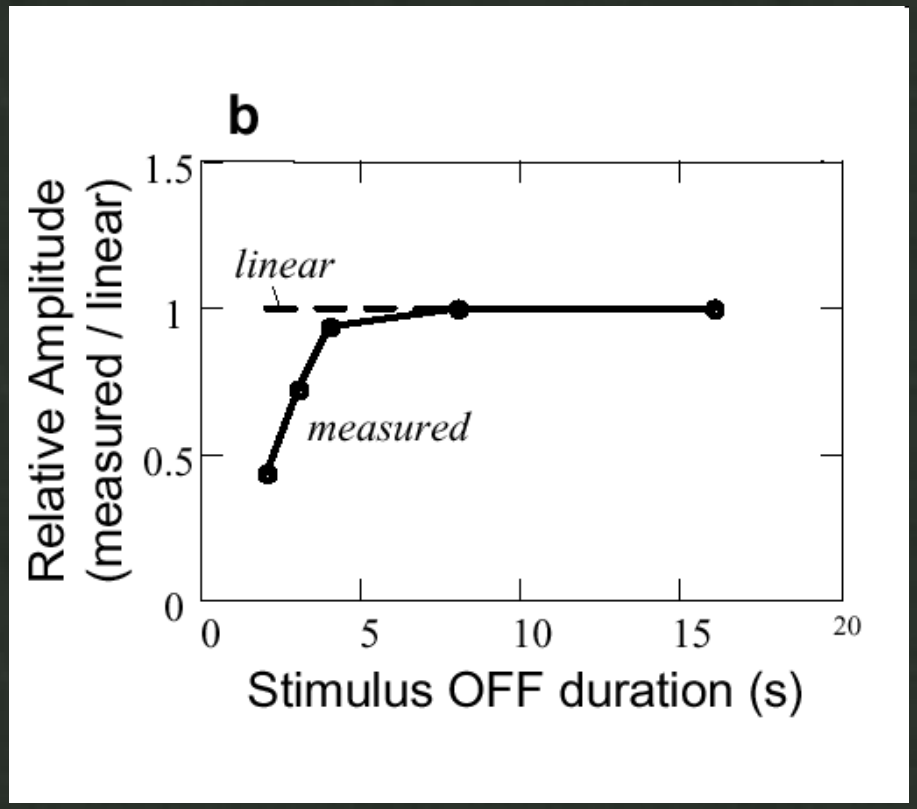
Interpretation

Linearity

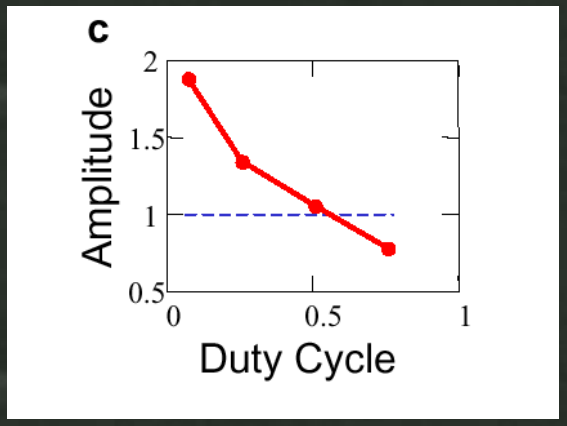
Increase: duration on



Decrease: duration off



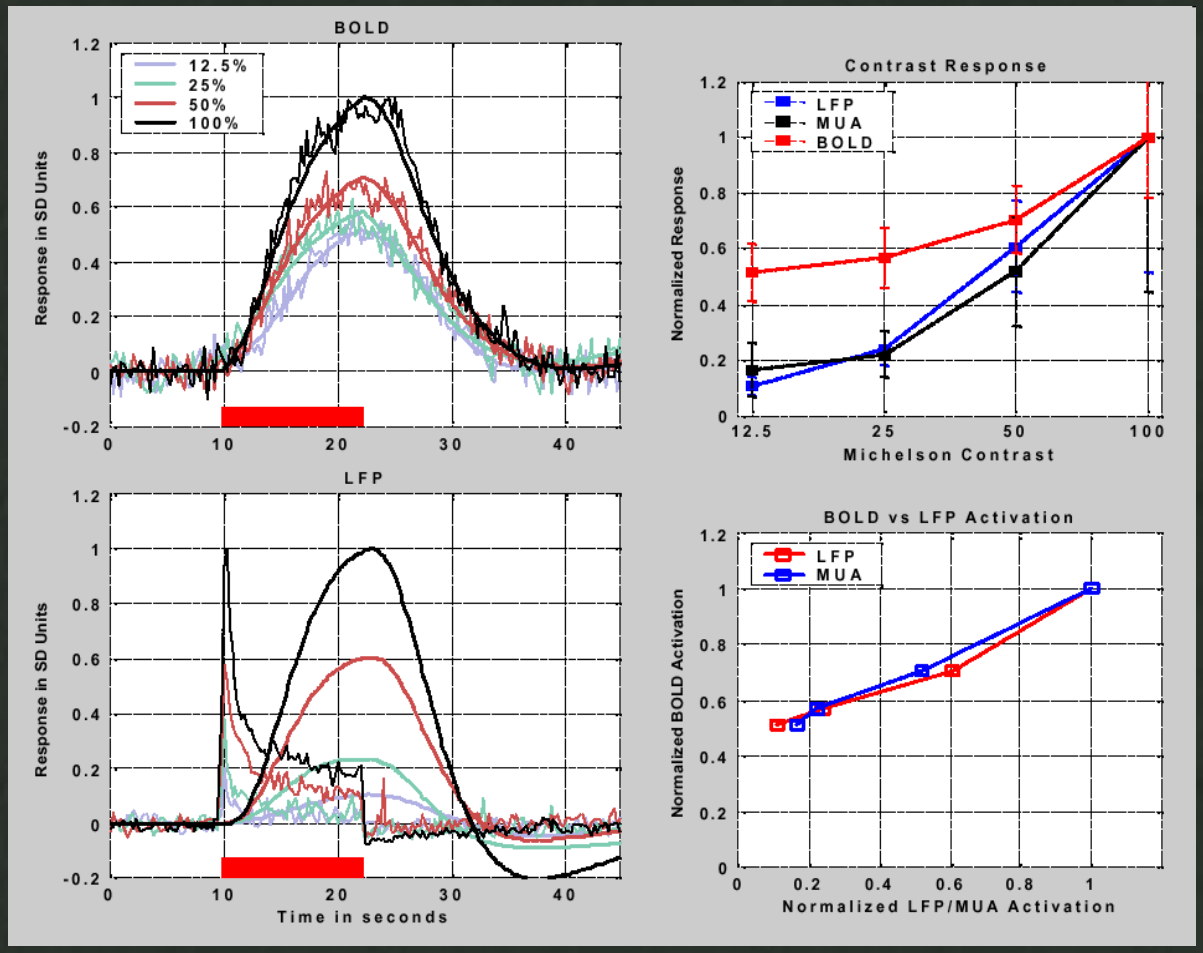
Increase: duty cycle



R.M. Birn, P. A. Bandettini. *NeuroImage, (in press)*

Interpretation

LFP vs Spiking

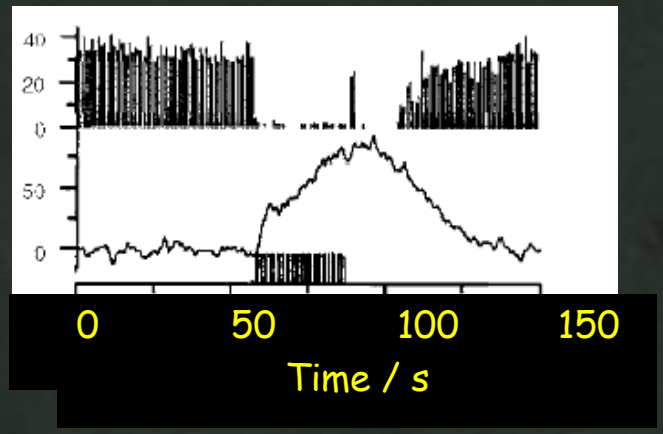


Logothetis et al. (2001) Nature, 412, 150-157

Interpretation

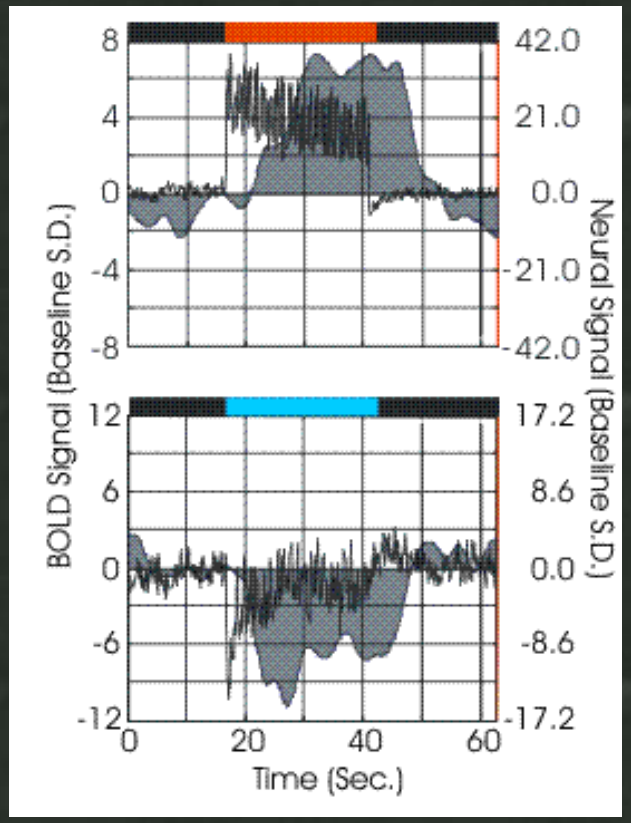
Inhibition and Decreases

Inhibition

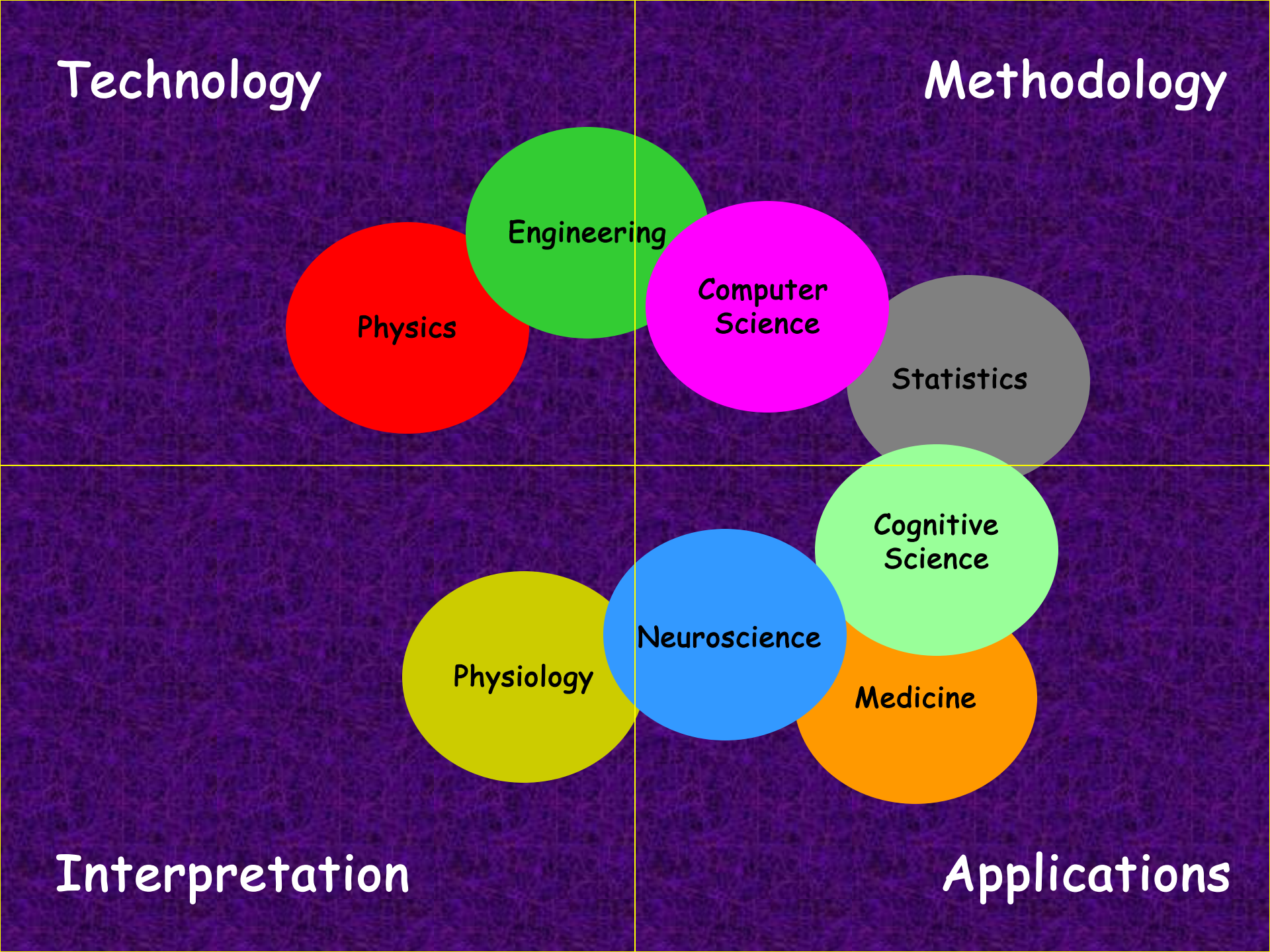


Mathiesen, et al (1998), J Physiol 512.2:555-566

Neg. BOLD



Schmuel et al. (2003) OHBM, 308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Applications

Applications

- Real Time Feedback
- Clinical Applications

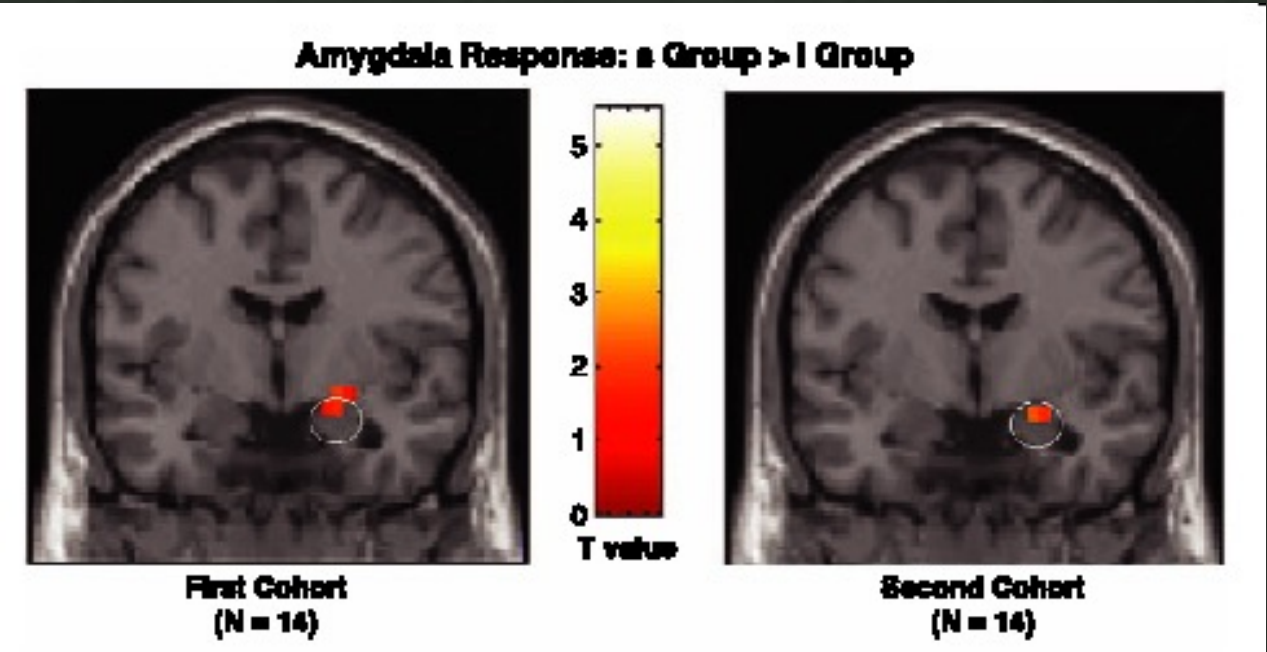
Applications

Clinical Applications

Comparison of two groups of *normal* individuals with differences in the Serotonin Transporter Gene

Serotonin Transporter Genetic Variation and the Response of the Human Amygdala

Ahmad R. Hariri,[1] Venkata S. Mattay,[1] Alessandro Tessitore,[1] Bhaskar Kolachana,[1] Francesco Fera,[1] David Goldman,[2] Michael F. Egan,[1] Daniel R. Weinberger[1]*



SCIENCE VOL 297 19 JULY 2002

Highest Citation Rate as of December 2004

Rank	Cit./Yr.	Tot. Cit.	Yr. Pub.	Authors	Journal, Vol, Pages	Type	Title
1	114	1485	1992	K. K. Kwong, J. W. Belliveau, et al.	PNAS,89,5675-5679	M	Dynamic Magnetic-Resonance-Imaging of Human Brain Activity During Primary Sensory Stimulation
2	112	448	2001	N. K. Logothetis, J. Pauls, et al.	Nature,412,150-157	I	Neurophysiological investigation of the basis of the fMRI signal
3	101	507	2000	R. Cabeza and L. Nyberg	Journal of Cog. Neuro.12,1-47	A	Imaging cognition II: An empirical review of 275 PET and fMRI studies
4	84	1095	1992	S. Ogawa, D. W. Tank, et al.	PNAS,89,5951-5955	M	Intrinsic Signal Changes Accompanying Sensory Stimulation - Functional Brain Mapping with Magnetic-Resonance-Imaging
5	82	655	1997	N. Kanwisher, J. McDermott et al.	Journal of Neuroscience,17,4302-4311	A	The fusiform face area: A module in human extrastriate cortex specialized for face perception
6	71	857	1993	P. A. Bandettini, A. Jesmanowicz, et al.	MRM 30,161-173	M	Processing Strategies for Time-Course Data Sets in Functional Mri of the Human Brain
7	67	336	2000	G. Bush, P. Luu et al.	TICS 4,215-222	A	Cognitive and emotional influences in anterior cingulate cortex
8	60	419	1998	C. S. Carter, T. S. Braver, et al.	Science,280,747-749	A	Anterior cingulate cortex, error detection, and the online monitoring of performance
9	58	231	2001	M. F. Egan, T. E. Goldberg et al.	PNAS,98,6917-6922	A	Effect of COMT Val(108/158) Met genotype on frontal lobe function and risk for schizophrenia
10	57	458	1997	J. D. Cohen, W. M. Perlstein, et al.	Nature,386,604-608	M/A	Temporal dynamics of brain activation during a working memory task
11	57	509	1996	R. W. Cox	Comp. and Biomed. Res. 29,162-173	M	AFNI: Software for analysis and visualization of functional magnetic resonance neuroimages
12	55	497	1996	A. Martin, C. L. Wiggs, et al.	Nature,379,649-652	A	Neural correlates of category-specific knowledge
13	53	745	1991	J. W. Belliveau, D. N. Kennedy, et al.	Science,254,716-719	M	Functional Mapping of the Human Visual-Cortex by Magnetic-Resonance-Imaging
14	53	691	1992	P. A. Bandettini, E. C. Wong, et al.	MRM, 25,390-397	M	Time Course Epi of Human Brain-Function During Task Activation
15	52	523	1995	M. I. Sereno, A. M. Dale, et al.	Science,268,889-893	M/A	Borders of Multiple Visual Areas in Humans Revealed by Functional Magnetic-Resonance-Imaging
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