Lecture	Day	Date	Room	Time	Topic	Lecturer	e-mail
1	Friday	6/5/15	Bldg 40, Rm 1201/3	2:00 PM	Introduction to Course & A history of fMRI	Peter Bandettini	bandettini@nih.gov
2	Monday	6/8/15	Bldg 49, Rm 1A51/9	2:00 PM	fMRI & MRI at the NIH today - an overview of the current research	Sean Marrett	marretts@mail.nih.gov
3	Wednesday	6/10/15	Bldg 40, Rm 1201/3	2:00 PM	AFNI plus SUMA: viewing your data	Bob Cox	robertcox@mail.nih.gov
4	Friday	6/12/15	Bldg 40, Rm 1201/3	2:00 PM	AFNI plus SUMA: analyzing your data	Bob Cox	robertcox@mail.nih.gov
5	Monday	6/15/15	Bldg 40, Rm 1201/3	2:00 PM	Stoked! Surfing Functional and Anatomical Connectivity Like Never Before	Ziad Saad	saadz@mail.nih.gov
6	Wednesday	6/17/15	Bldg 40, Rm 1201/3	2:00 PM	Basics of MRI - and basic safety in MRI	Vinai Roopchansingh	roopchansinghv@mail.nih.gov
7	Friday	6/19/15	Bldg 40, Rm 1201/3	2:00 PM	Artifacts in MRI and how to identify them	Vinai Roopchansingh	roopchansinghv@mail.nih.gov
8	Monday	6/22/15	Bldg 40, Rm 1201/3	2:00 PM	Advanced MRI and fMRI Acquisition Methods	Souheil Inati	souheil.inati@nih.gov
9	Wednesday	6/24/15	Bldg 40, Rm 1201/3	2:00 PM	fMRI: What can and cannot be done?	Bob Cox	robertcox@mail.nih.gov
10	Friday	6/26/15	Bldg 40, Rm 1201/3	2:00 PM	Functional MRI contrast and the limits of spatial and temporal resolution	Peter Bandettini	bandettini@nih.gov
11	Monday	6/29/15	Bldg 40, Rm 1201/3	2:00 PM	fMRI Paradigm Designs and Processing Methods	Peter Bandettini	bandettini@nih.gov
12	Wednesday	7/1/15	Bldg 40, Rm 1201/3	2:00 PM	fMRI methods that never quite caught on	Peter Bandettini	bandettini@nih.gov
13	Monday	7/6/15	Bldg 40, Rm 1201/3	2:00 PM	Basic tradeoffs/constraints in fMRI methodology and applications	Jen Evans	jennifer.evans@nih.gov
14	Wednesday	7/8/15	Bldg 40, Rm 1201/3	2:00 PM	Perfusion MRI	Lalith Talagala	talagalal@mail.nih.gov
15	Friday	7/10/15	Bldg 40, Rm 1201/3	2:00 PM	Statistics of fMRI	Gang Chen	gangchen@mail.nih.gov
16	Monday	7/13/15	Bldg 40, Rm 1201/3	2:00 PM	How do we know what signal is neural and what is not?	Dan Handwerker	handwerkerd@mail.nih.gov
17	Wednesday	7/15/15	Bldg 35A, Rm 640	2:00 PM	Multi-modal imaging, EEG-fMRI	Silvina Horovitz	silvina.horovitz@nih.gov
18	Friday	7/17/15	Bldg 40, Rm 1201/3	2:00 PM	Computational Modeling of fMRI	Biyu He	biyu.he@nih.gov
19	Monday	7/20/15	Bldg 40, Rm 1201/3	2:00 PM	fMRI Mediation analysis for fMRI based pain assessment	Lauren Atlas	lauren.atlas@nih.gov
20	Wednesday	7/22/15	Bldg 40, Rm 1201/3	2:00 PM	Approaches to functional activity mapping during natural viewing	Brian Russ	russbe@mail.nih.gov
21	Friday	7/24/15	Bldg 40, Rm 1201/3	2:00 PM	Studying CNS diseases with advanced MRI	Pascal Sati	pascal.sati@nih.gov
22	Monday	7/27/15	Bldg 40, Rm 1201/3	2:00 PM	Quantitative MRI	Govind Bhagavatheeshwaran	govind.bhagavatheeshwaran@nih.gov
23	Wednesday	7/29/15	Bldg 40, Rm 1201/3	2:00 PM	Measuring structural brain change over time	Adam Thomas	adamt@nih.gov
24	Friday	7/31/15	Bldg 40, Rm 1201/3	2:00 PM	Brain Reading with fMRI	Chris Baker	bakerchris@mail.nih.gov
25	Monday	8/3/15	Bldg 40, Rm 1201/3	2:00 PM	Anatomical and Functional Neuroimaging in Animal Models	Afonso Silva	SilvaA@ninds.nih.gov
26	Wednesday	8/5/15	Bldg 40, Rm 1201/3	2:00 PM	fMRI Data Sharing	Dan Handwerker	handwerkerd@mail.nih.gov
27	Friday	8/7/15	Bldg 49, Rm 1A51/9	2:00 PM	fMRI of Mood Disorders	Allison Nugent	nugenta@gmail.com
28	Monday	8/10/15	Bldg 40, Rm 1201/3	2:00 PM	Resting State fMRI	Catie Chang	catie.chang@nih.gov
29	Wednesday	8/12/15	Bldg 40, Rm 1201/3	2:00 PM	Dynamic Resting State fMRI assessment	Javier Gonzalez-Castillo	javier.gonzalez-castillo@nih.gov
30	Friday	8/14/15	Bldg 40, Rm 1201/3	2:00 PM	Approaches to dealing with motion in resting state fMRI	Jonathan Power	jonathan.power@nih.gov
31	Monday	8/17/15	Bldg 40, Rm 1201/3	2:00 PM	Multi-echo EPI for resting state and activation based fMRI	Javier Gonzalez-Castillo	javier.gonzalez-castillo@nih.gov
32	Wednesday	8/19/15	Bldg 40, Rm 1201/3	2:00 PM	Methods for whole-brain comparisons of resting state connectivity	Steve Gotts	gottss@mail.nih.gov
33	Friday	8/21/15	Bldg 40, Rm 1201/3	2:00 PM	Prospective motion correction - is it better?	Andy Derbyshire	john.derbyshire@nih.gov
34	Monday	8/24/15	Bldg 40, Rm 1201/3	2:00 PM	T1 Contrast, MPRAGE and MT	Peter van Gelderen	pg24y@nih.gov
35	Wednesday	8/26/15	Bldg 40, Rm 1201/3	2:00 PM	fMRI and Development	Danny Pine	pined@mail.nih.gov
36	Friday	8/28/15	Bldg 40, Rm 1201/3	2:00 PM	Diffusion MRI	Joelle Sarlls	sarllsjo@mail.nih.gov
37	Monday	8/31/15	Bldg 40, Rm 1201/3	2:00 PM	What you can and can't do with diffusion MRI	Carlo Pierpaoli	cp1a@nih.gov
38	Wednesday	9/2/15	Bldg 40, Rm 1201/3	2:00 PM	Contentious Issues in fMRI	Peter Bandettini	bandettini@nih.gov
39	Friday	9/4/15	Bldg 49, Rm 1A51/9	2:00 PM	Is the Future of fMRI in the assessment of the individual?	Peter Bandettini	bandettini@nih.gov

A Brief History of fMRI

Peter A. Bandettini, Ph.D.

Section on Functional Imaging Methods

Laboratory of Brain and Cognition

http://fim.nimh.nih.gov

&

Functional MRI Facility

http://fmrif.nimh.nih.gov

ISSN 1053-8119
Volume 62, Issue 2, August 15, 2012

ELSEVIER

NeuroImage

Editor-in-Chief
Peter Bandettini

Special Issue
20 Years of fMRI: The Science and the Stories

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Peter Jezzard	Alan Koretsky	Fahmeed Hyder	Robert Savoy	David Norris	Steve Engel	Klaas Enno Stephan	John Baptiste Poline	Andrew Blamire	Kamil Ugurbil, Seiji Ogawa, Ravi Menon, Seong-Gi Kim	Mark Woolrich
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Rainer Goebel	Orientation Column fMRI data from Noam Harel	Steve Petersen, Joseph Dubis	Tom Talavage	Vince Clark	Gary Glover	Russ Poldrack	Seiji Ogawa	Eric Wong	Deb Hall	Krish Singh
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	3	The coupling controversy	Peter Fox
	4	Early development of arterial spin labeling to measure regional brain blood flow by MRI	Alan Korestky
	5	Finding the BOLD effect in brain images	Seiji Ogawa
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	7	Development of functional Imaging in the human brain (fMRI); the university of Minnesota experience	Kamil Ugurbil
	8	Sewer pipe, epoxy, wire, and finger tapping: the start of fMRI at the Medical College of Wisconsin	Peter Bandettini
	9	The NIH experience in first advancing fMRI	Robert Turner
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	12	Correction of geometric distortion in fMRI data	Peter Jezzard
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	38	Multivariate patterns analysis of fMRI: the early beginnings	Jim Haxby
	39	A short history of causal modeling of fMRI data	Klaas Enno Stephan & Alard Roebroeck
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	50	Voodoo and circularity errors	Ed Vul
	51	Diffusion modulation of the fMRI signal	Alan Song
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	53	Intracortical Recordings and fMRI: An attempt to study operational modules and networks	Nikos Logothetis
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	55	Linear systems analysis of the fMRI signal	Geoff Boynton
	56	Quantitative fMRI and oxidative neuroenergetics	Fahmeed Hyder & Douglas Rothman
	57	The meaning of fMRI signals	Arno Villringer
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	61	The continuing challenge of understanding and modeling hemodynamic variation in fMRI	Dan Handwerker
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	65	Neuronal inhibition and excitation, and the dichotomic control of brain hemodynamic and oxygen responses	Martin Lauritzen
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	72	The story of the initial dip in fMRI	Xiaoping Hu
	73	Spin-echo fMRI: the poor relation?	David Norris
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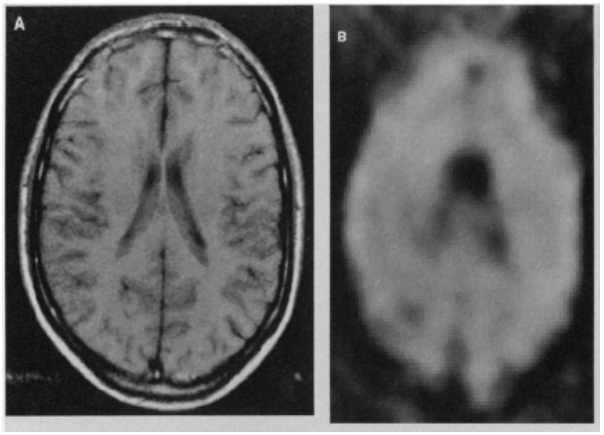
	95	The future of fMRI connectivity	Steve Smith
	96	The future of fMRI in clinical medicine	Ed Bullmore
	97	Future trends in Neuroimaging: neuronaprocesses as expressed within real-life social contexts	Uri Hasson
	98	The future of fMRI with perfusion imaging	Geoff Aguirre
	99	The future of fMRI and genetics research	Andreas Meyer-Lindenberg
	100	The future of functionally related structural change assessment	Heidi Johansen-Berg
	101	The future of the human connectome	David van Essen & Kamil Ugurbil
	102	The future of susceptibility contrast for assessment of anatomy and function	Jurgen Reichenbach
	103	fMRI at 20: Has it changed the world?	Bruce Rosen

Functional Magnetic Resonance Imaging in Medicine and Physiology

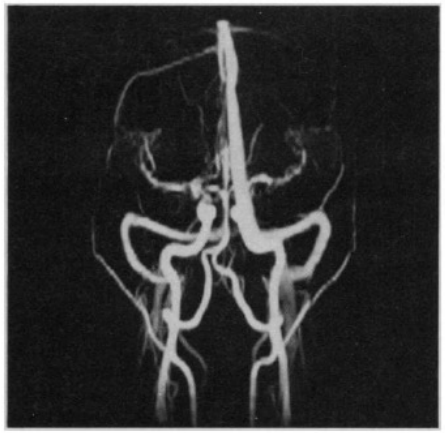
Chrit T. W. Moonen, Peter C. M. van Zijl, Joseph A. Frank, Denis Le Bihan, Edwin D. Becker

(1990) *Science*, 250, 53-61.

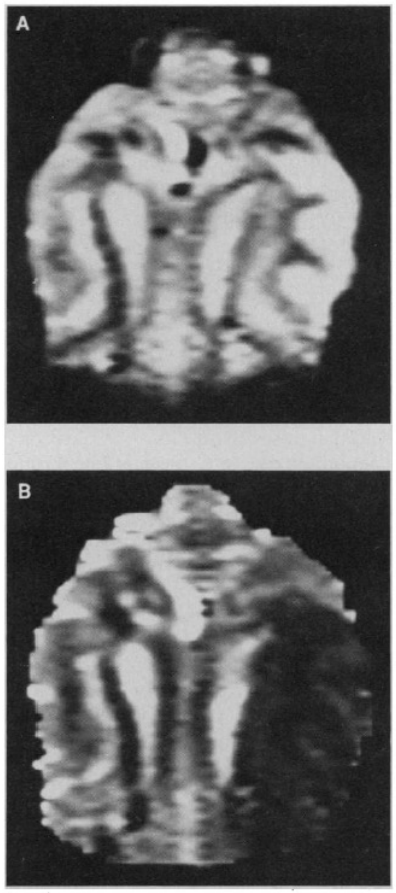
metabolic imaging (NAA)



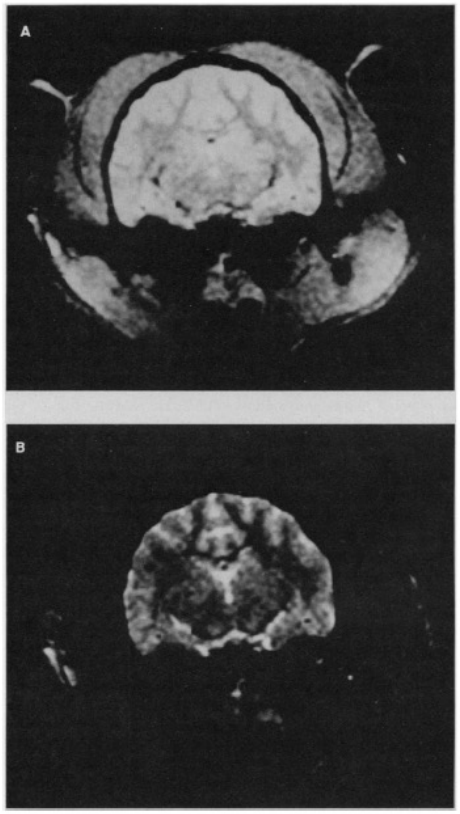
angiography

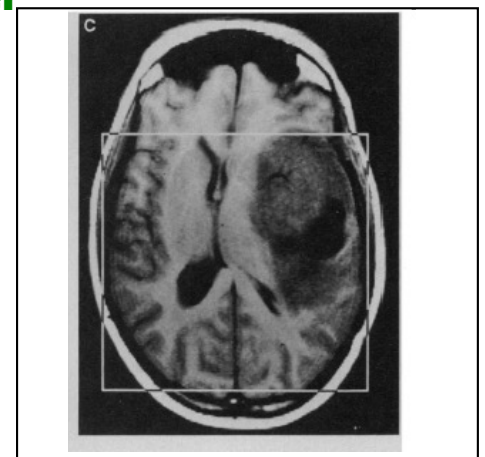


Diffusion

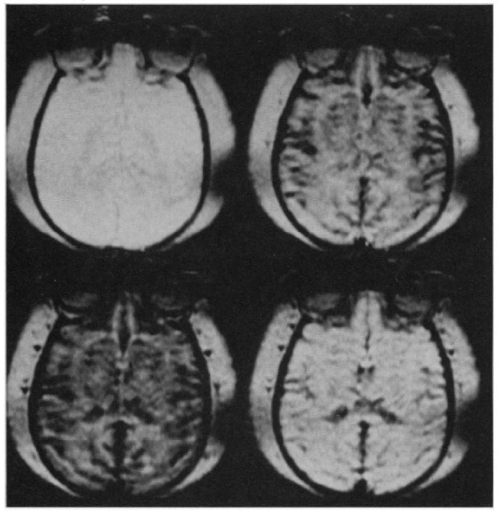


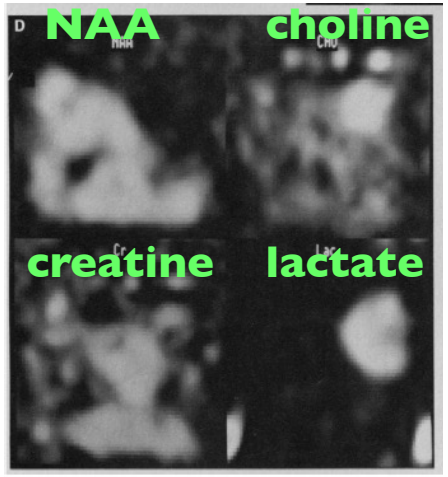
magnetization transfer





Gadolinium perfusion





What we were excited about then…

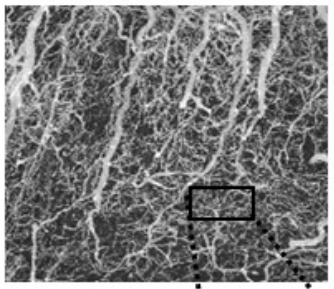
IVIM: Intravoxel Incoherent Motion

Denis Le Bihan, MD, PhD • Eric Breton, MS • Denis Lallemand, MD
• Marie-Louise Aubin, MD • Jacqueline Vignaud, MD • Maurice Laval-Jeantet, MD

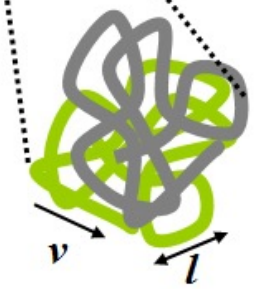
Radiology 1988; 168:497-505

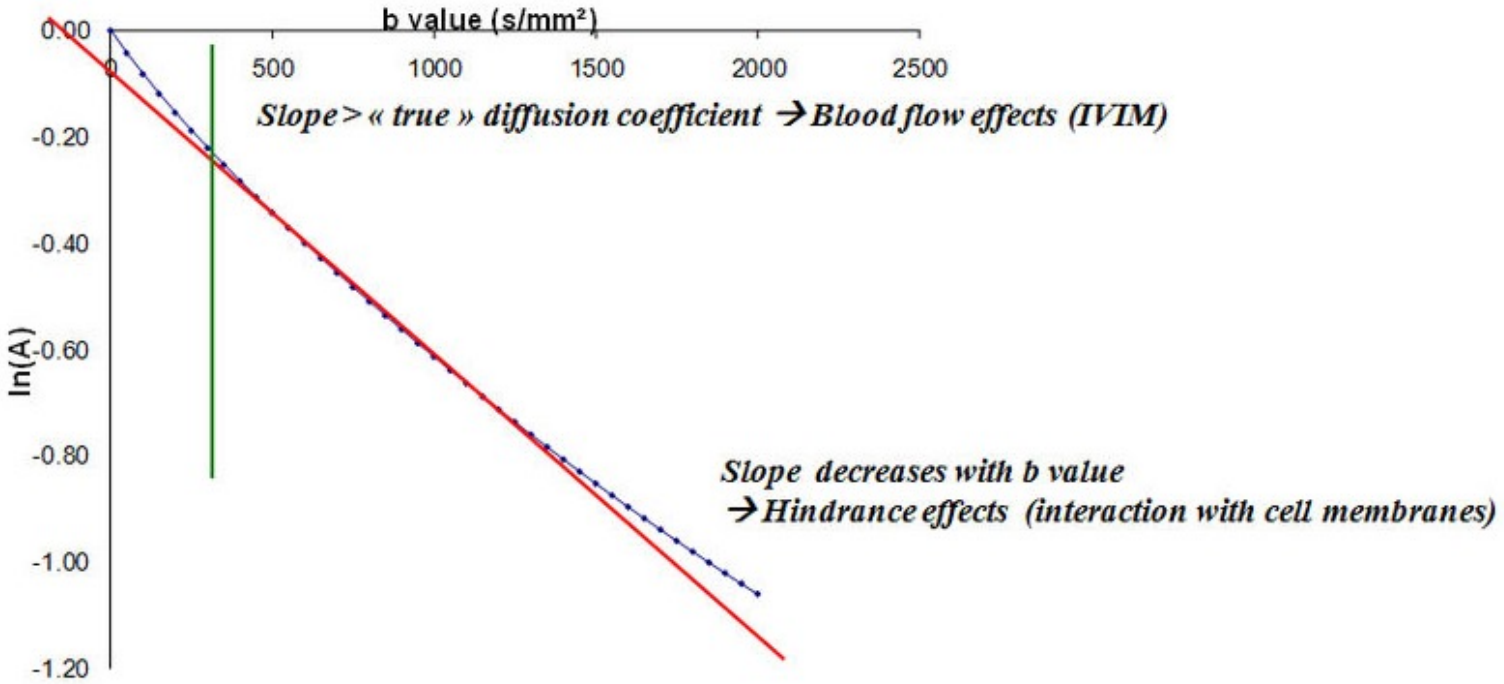
Separation of Diffusion and Perfusion in Intravoxel Incoherent Motion MR Imaging[1]

IVIM: Intravoxel Incoherent Motion



The concept introduced by D. Le Bihan is that water flowing in randomly oriented capillaries (at the voxel level) mimics a random walk ("pseudo-diffusion")



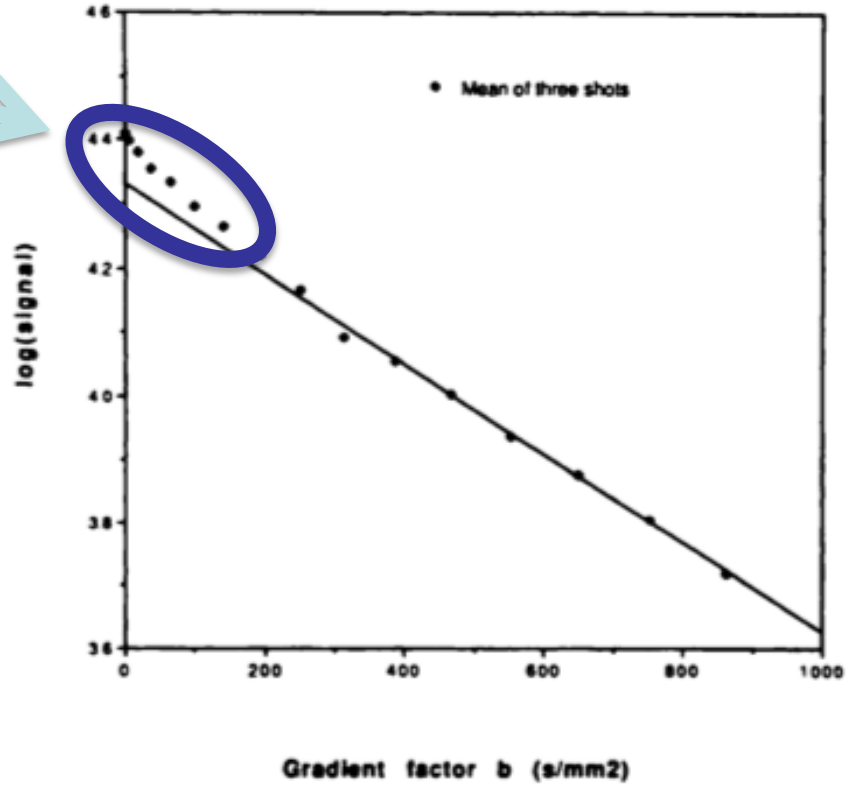


Robert Turner, PhD • Denis Le Bihan, MD, PhD • Joseph Maier, MS (EEE) •
Robert Vavrek, MS (EEE) • L. Kyle Hedges, PhD • James Pekar, PhD

Echo-Planar Imaging of Intravoxel Incoherent Motion[1]

Radiology 1990; 177:407–414

IVIM
Perfusion?



How it all came together…

Five Key Factors For The Emergence of Functional MRI

1. **Magnetic properties of red blood cells**
2. **Activation related hemodynamic changes**
3. **Spatial scale of brain activation**
4. **Echo Planar Imaging**
5. **Prevalence of MRI scanners**

Five Key Factors For The Emergence of Functional MRI

1. Magnetic properties of red blood cells
2. Activation related hemodynamic changes
3. Spatial scale of brain activation
4. Echo Planar Imaging
5. Prevalence of MRI scanners

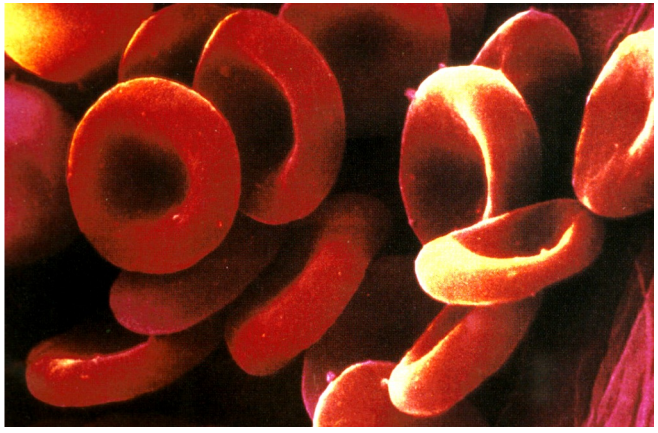
Magnetic Properties of Blood

L. Pauling, C. D. Coryell, *Proc.Natl.Acad. Sci. USA 22, 210-216*, **1936**.

K.R. Thulborn, J. C. Waterton, et al., *Biochim. Biophys. Acta. 714: 265-270*, **1982**.

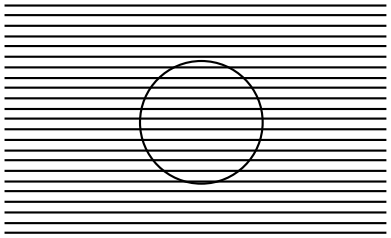
S. Ogawa, T. M. Lee, A. R. Kay, D. W. Tank, *Proc. Natl. Acad. Sci. USA 87, 9868-9872*, **1990**.

Turner, R., Lebihan, D., Moonen, C. T. W., Despres, D. & Frank, J. *Magnetic Resonance in Medicine,* 22, 159-166, **1991.**

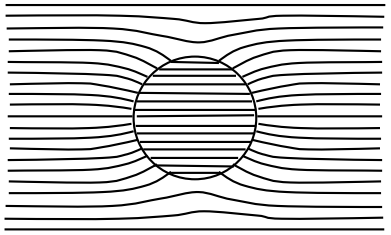


red blood cells

oxygenated



deoxygenated



BOLD contrast investigation started in 1936…or even 1845.

THE MAGNETIC PROPERTIES AND STRUCTURE OF HEMOGLOBIN, OXYHEMOGLOBIN AND CARBONMONOXYHEMOGLOBIN

BY LINUS PAULING AND CHARLES D. CORYELL

GATES CHEMICAL LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY

Communicated March 19, 1936

Over ninety years ago, on November 8, 1845, Michael Faraday investigated the magnetic properties of dried blood and made a note "Must try recent fluid blood." If he had determined the magnetic susceptibilities of arterial and venous blood, he would have found them to differ by a large amount (as much as twenty per cent for completely oxygenated and completely deoxygenated blood); this discovery without doubt would have excited much interest and would have influenced appreciably the course of research on blood and hemoglobin.[1]

Continuing our investigations of the magnetic properties and structure of hemoglobin and related substances,[2] we have found oxyhemoglobin and carbonmonoxyhemoglobin to contain no unpaired electrons, and ferrohemoglobin (hemoglobin itself) to contain four unpaired electrons per heme. The description of our experiments and the interpretation and discussion of the results are given below.

Biochimica et Biophysica Acta, 714 (1982) 265–270
Elsevier Biomedical Press

BBA 20122

OXYGENATION DEPENDENCE OF THE TRANSVERSE RELAXATION TIME OF WATER PROTONS IN WHOLE BLOOD AT HIGH FIELD

KEITH R. THULBORN, JOHN C. WATERTON *, PAUL M. MATTHEWS and GEORGE K. RADDA

Department of Biochemistry, University of Oxford, South Parks Road, Oxford OX1 3QU (U.K.)

(Received August 4th, 1981)

Key words: Oxygenation dependence; Transverse relaxation time; Water proton; High field NMR; (Whole blood)

At high and medium magnetic field, the transverse NMR relaxation rate (T_2^{-1}) of water protons in blood is determined predominantly by the oxygenation state of haemoglobin. T_2^{-1} depends quadratically on the field strength and on the proportion of haemoglobin that is deoxygenated. Deoxygenation increases the volume magnetic susceptibility within the erythrocytes and thus creates local field gradients around these cells.From volume susceptibility measurements and the dependence of T_2^{-1} on the pulse rate in the Carr-Purcell-Meiboom-Gill experiment, we show that the increase in T_2^{-1} with increasing blood deoxygenation arises from diffusion of water through these field gradients.

Oxygenation Changes T2

Biochimica et Biophysica Acta, 714 (1982) 265–270
Elsevier Biomedical Press

BBA 20122

OXYGENATION DEPENDENCE OF THE TRANSVERSE RELAXATION TIME OF WATER PROTONS IN WHOLE BLOOD AT HIGH FIELD

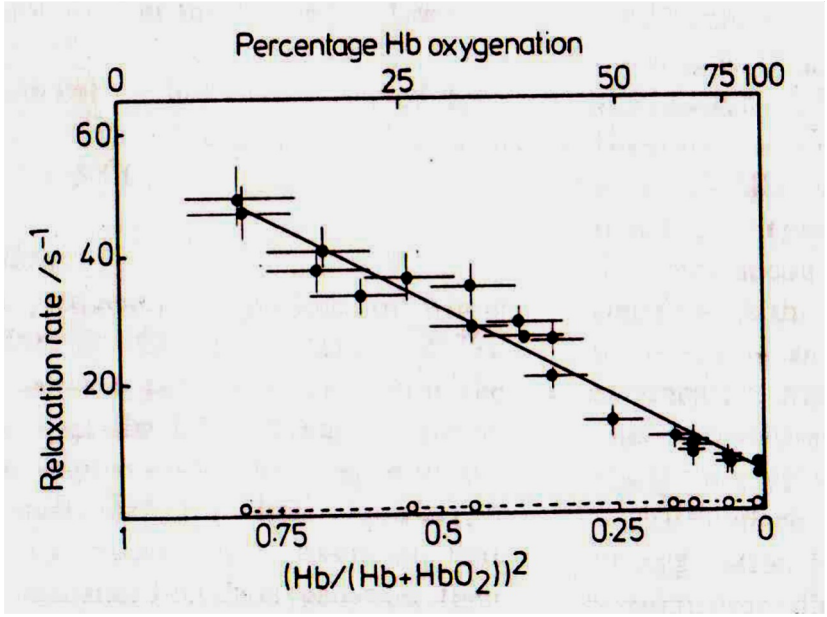
KEITH R. THULBORN, JOHN C. WATERTON *, PAUL M. MATTHEWS and GEORGE K. RADDA

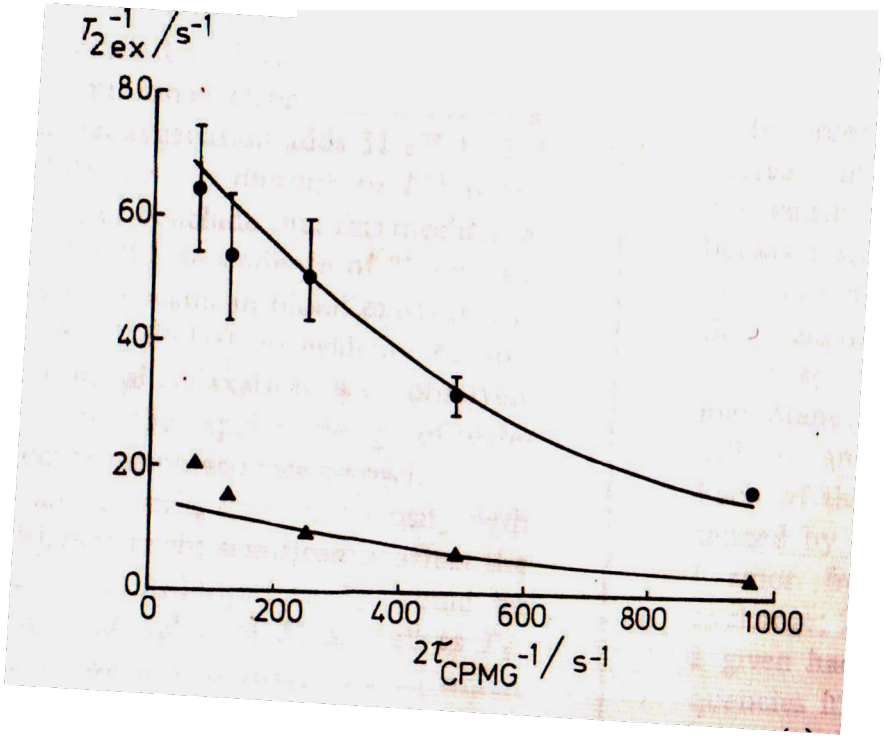
Department of Biochemistry, University of Oxford, South Parks Road, Oxford OX1 3QU (U.K.)

(Received August 4th, 1981)

R2 effect is due to bulk susceptibility and not dipole-dipole interaction

Blood R2 proportional to Oxygenation





...Six years later...

Oxygenation-Sensitive Contrast in Magnetic Resonance Image of Rodent Brain at High Magnetic Fields

SEIJI OGAWA, TSO-MING LEE, ASHA S. NAYAK,* AND PAUL GLYNN

AT&T Bell Laboratories, Murray Hill, New Jersey 07974

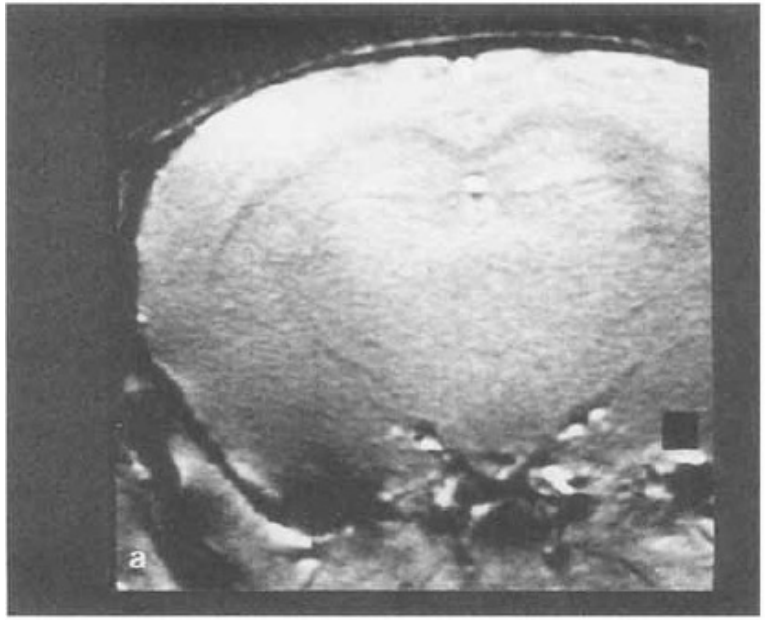
Received November 30, 1988; accepted June 20, 1989

At high magnetic fields (7 and 8.4 T), water proton magnetic resonance images of brains of live mice and rats under pentobarbital anesthetization have been measured by a gradient echo pulse sequence with a spatial resolution of 65 × 65-μm pixel size and 700-μm slice thickness. The contrast in these images depicts anatomical details of the brain by numerous dark lines of various sizes. These lines are absent in the image taken by the usual spin echo sequence. They represent the blood vessels in the image slice and appear when the deoxyhemoglobin content in the red cells increases. This contrast is most pronounced in an anoxy brain but not present in a brain with diamagnetic oxy or carbon monoxide hemoglobin. The local field induced by the magnetic susceptibility change in the blood due to the paramagnetic deoxyhemoglobin causes the intra voxel dephasing of the water signals of the blood and the surrounding tissue. This oxygenation-dependent contrast is appreciable in high field images with high spatial resolution.

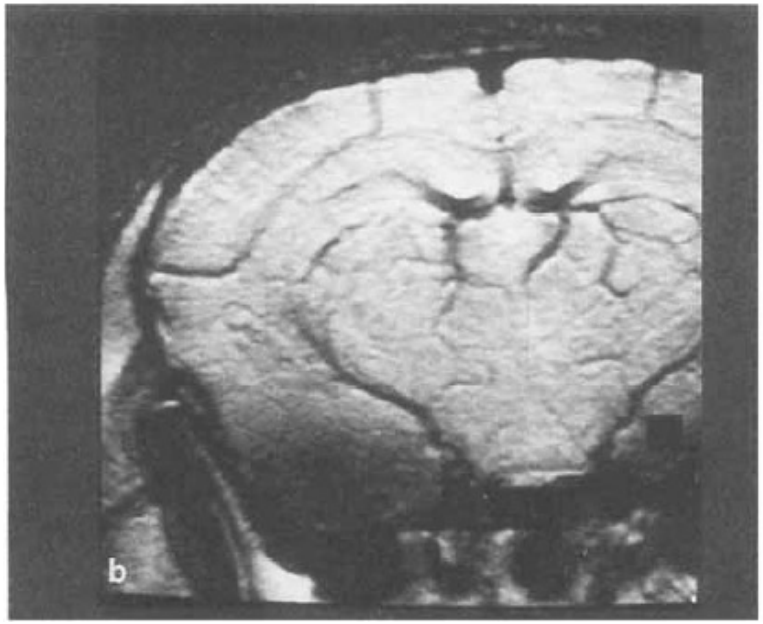
in vivo

in vitro

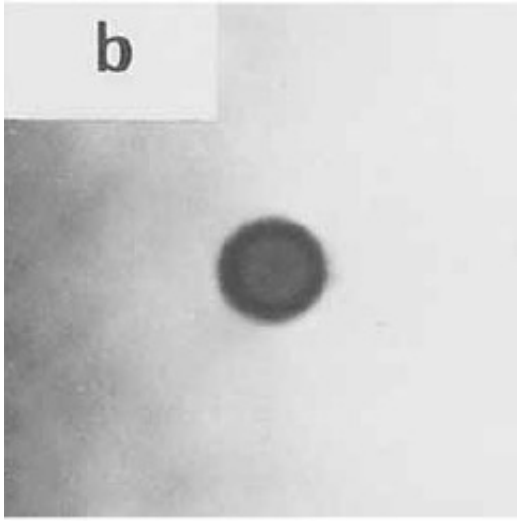
100% O_2



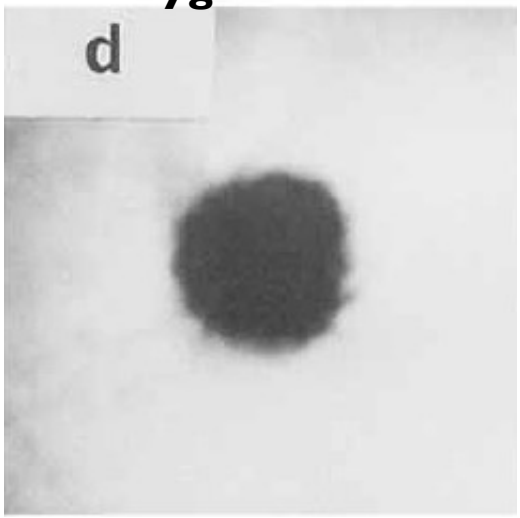
20% O_2



100% oxygenated blood

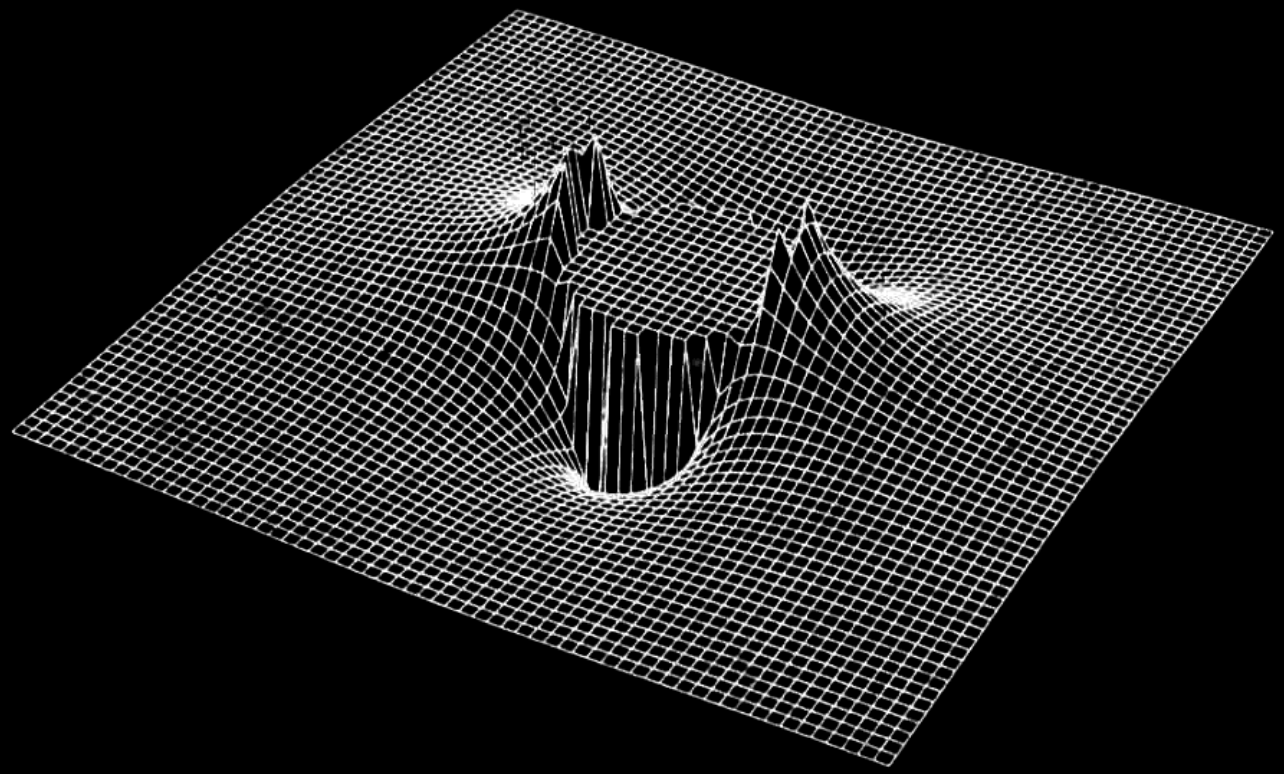


0% oxygenated blood



S. Ogawa, T.-M. Lee, A. S. Nayak, P. Glynn, Magn. Reson. Med, 14, 68-78 (1990)

Susceptibility-Induced Field Distortion in the Vicinity of a Microvessel $\perp$ to B_O.



Magnetic Resonance in Medicine
“30 papers that shaped the field.”

MAGNETIC RESONANCE IN MEDICINE 22, 159–166 (1991)

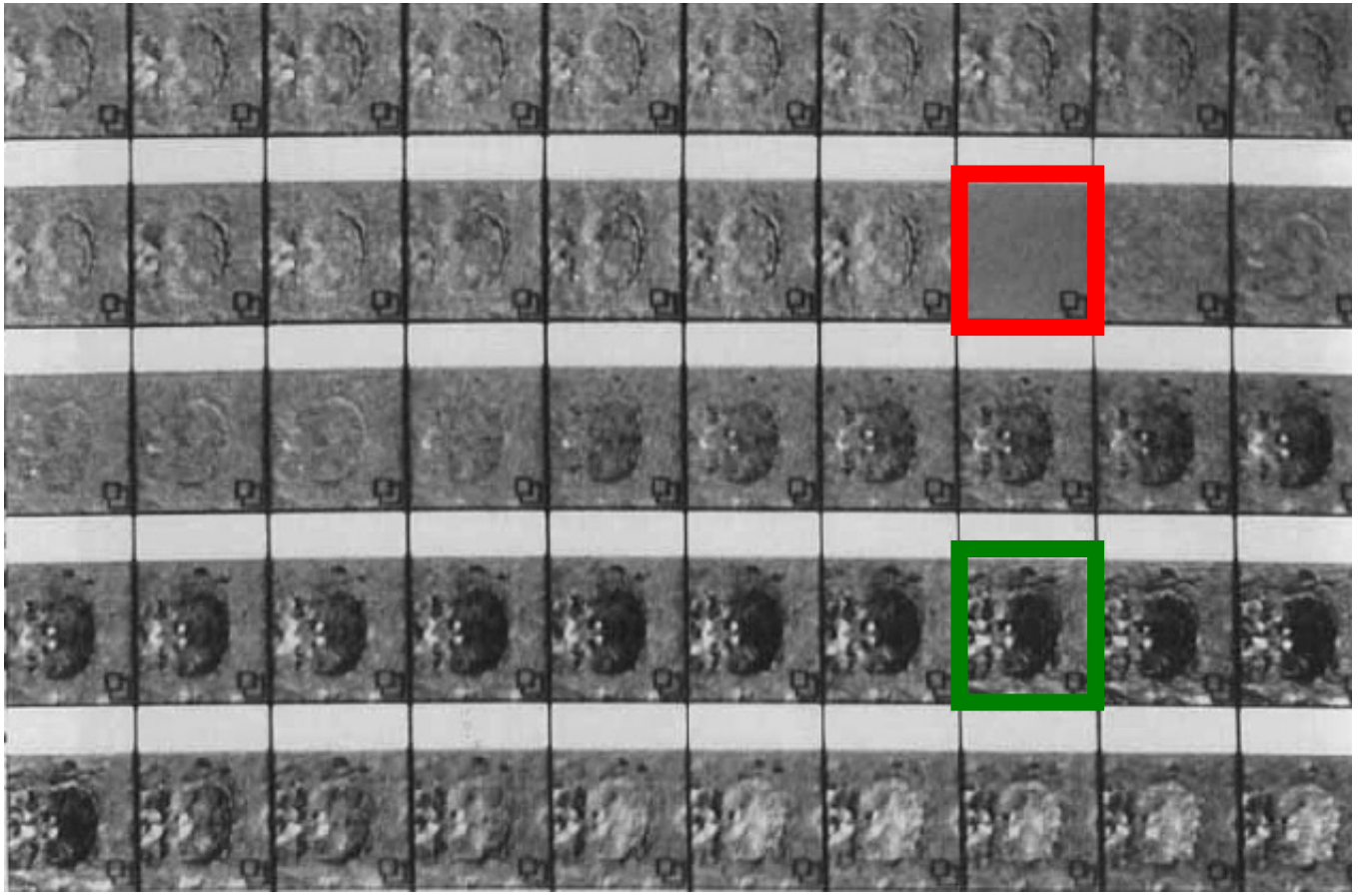
Echo-Planar Time Course MRI of Cat Brain Oxygenation Changes

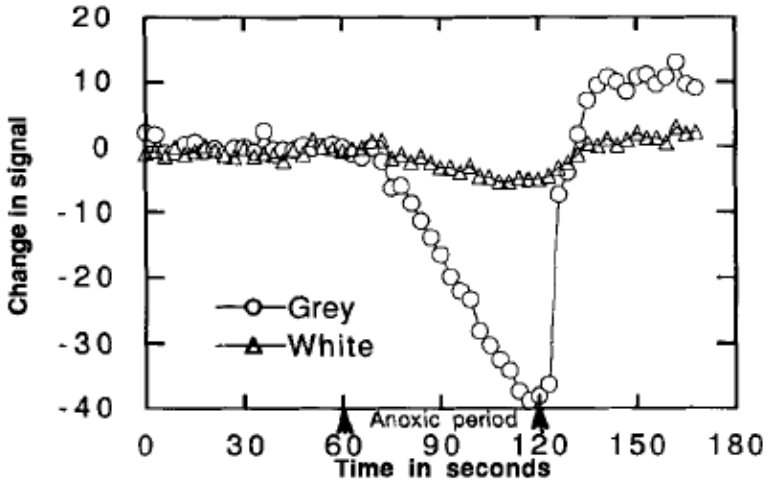
ROBERT TURNER,*† DENIS LE BIHAN,‡ CHRIT T. W. MOONEN,§
DARYL DESPRES,§ AND JOSEPH FRANK‡

* *Laboratory of Cardiac Energetics,* ‡ *Diagnostic Radiology Department, and* § *In Vivo NMR Research Center, National Institutes of Health, Bethesda, Maryland 20892*

Received June 25, 1991; revised August 7, 1991

When deoxygenated, blood behaves as an effective susceptibility contrast agent. Changes in brain oxygenation can be monitored using gradient-echo echo-planar imaging. With this technique, difference images also demonstrate that blood oxygenation is increased during periods of recovery from respiratory challenge.





R. Turner, D. LeBihan, C.T.W. Moonen, D. Despres, J. Frank, Magn. Reson. Med, 22, 159-166 (1991)

Ogawa predicted fMRI but got the sign wrong…

"...we expect this oxygenation-sensitive contrast could be used to monitor regional oxygen usages in the brain. When some region in a brain is much more active than other regions, the active region could show darker lines in the image because of the increased level of deoxyhemoglobin resulting from higher oxygen consumption."

"Therefore, in addition to the anatomy of the brain, one aspect of its physiology can be studied by the MRI of water"

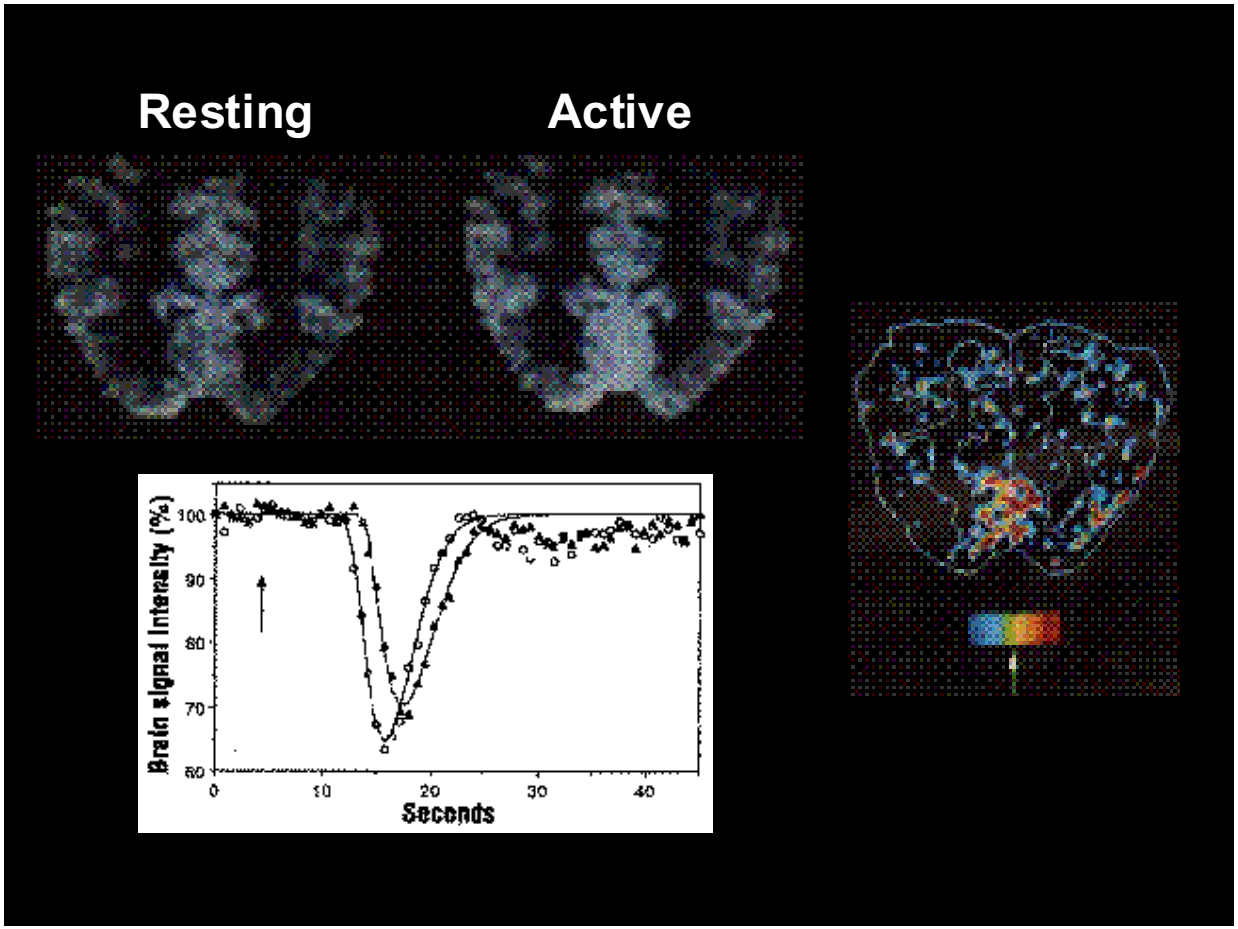
Oxygenation-Sensitive Contrast in Magnetic Resonance Image of Rodent Brain at High Magnetic Fields, Seiji Ogawa, Tso-Ming Lee, Asha S. Nayak, and Paul Glynn.**Magnetic Resonance in Medicine 14, 68-78 (1990).**

Five Key Factors For The Emergence of Functional MRI

1. Magnetic properties of red blood cells
2. Activation related hemodynamic changes
3. Spatial scale of brain activation
4. Echo Planar Imaging
5. Prevalence of MRI scanners

The First Functional MRI Results (MGH)

Susceptibility Contrast agent bolus injection and time series collection of T2 - weighted images



The First Functional MRI Results (MGH)

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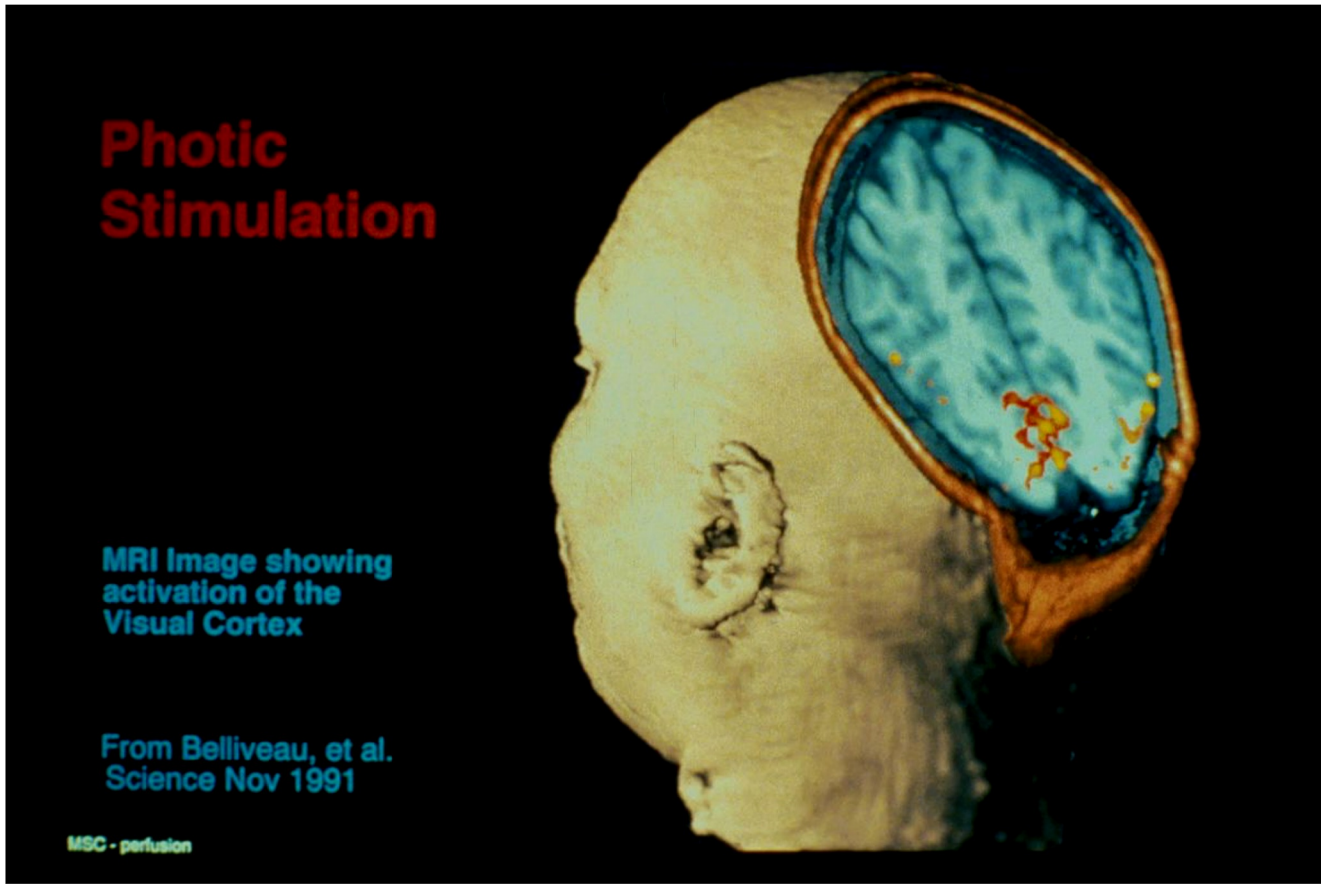


The MGH Gang

Jack Belliveau, Explorer of the Brain Using M.R.I., Dies at 55

By **BENEDICT CAREY** MARCH 9, 2014

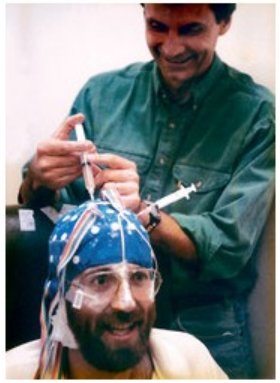
Jack Belliveau

Jack Belliveau, a Harvard scientist whose quest to capture the quicksilver flare of thought inside a living brain led to the first magnetic resonance image of human brain function, died on Feb. 14 in San Mateo, Calif. He was 55.

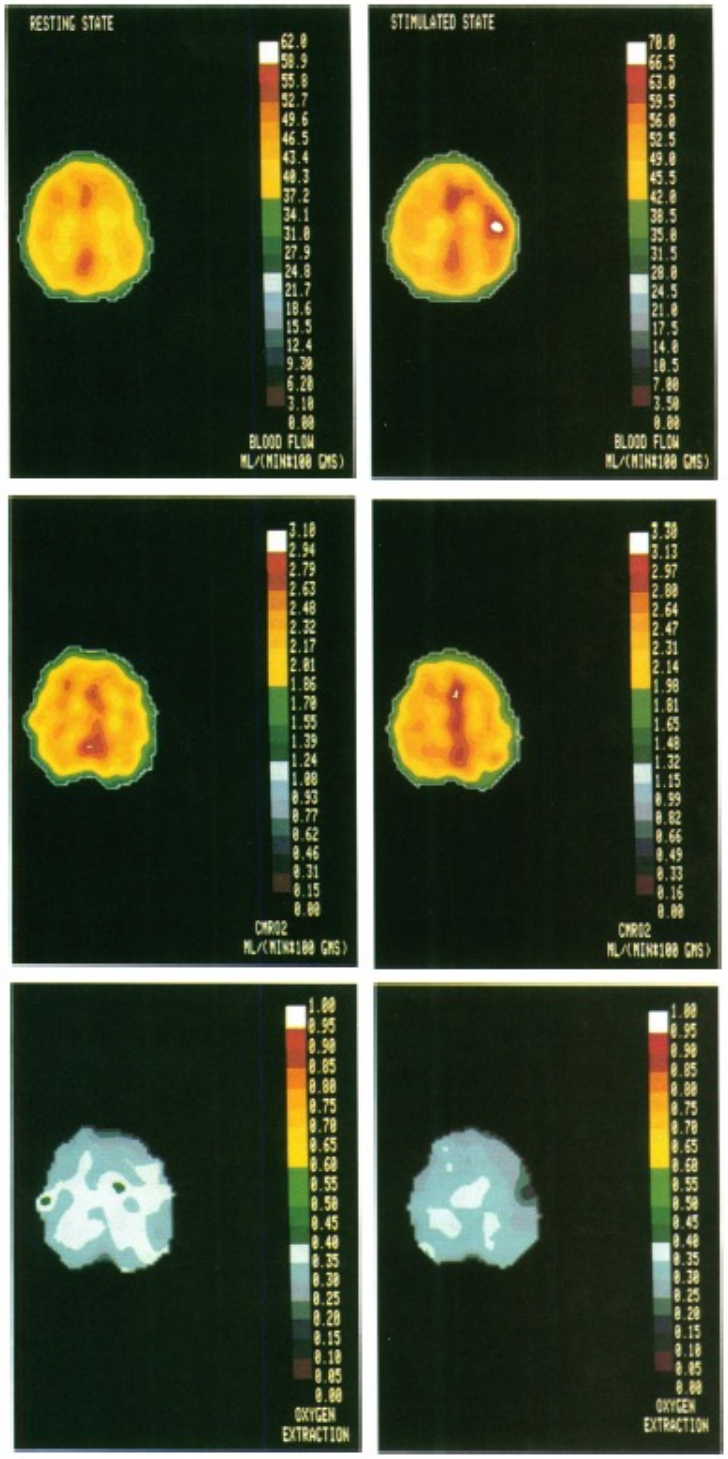
The cause was complications of a gastrointestinal disorder, said his wife, Brigitte Poncelet-Belliveau, a researcher who worked with him at the Athinoula A. Martinos Center for Biomedical Imaging at Massachusetts General Hospital. He lived in Boston. His wife said he died suddenly while visiting an uncle at his childhood home, which he owned.

Dr. Belliveau was a 30-year-old graduate student at the Martinos Center when he hatched a scheme to "see" the neural trace of brain activity. Doctors had for decades been taking X-rays and other images of the brain to look for tumors and other lesions and to assess damage from brain injuries. Researchers had also mapped blood flow using positron emission tomography scans, but that required making and handling radioactive trace chemicals, whose signature vanished within minutes. Very few research centers had the technical knowledge or the machinery to pull it off.

Dr. Belliveau tried a different approach. He had developed a technique to track blood flow, called dynamic susceptibility contrast, using an M.R.I. scanner that took split-second images, faster than was usual at the time. This would become a standard technique for assessing blood perfusion in stroke patients and others, but Dr. Belliveau thought he would try it to spy on a normal brain in the act of thinking or perceiving.



Jack Belliveau, seated for an experimental EEG, with his colleague Gregory Simpson. Harvard Medical School



Proc. Natl. Acad. Sci. USA
Vol. 83, pp. 1140–1144, February 1986
Neurobiology

Focal physiological uncoupling of cerebral blood flow and oxidative metabolism during somatosensory stimulation in human subjects

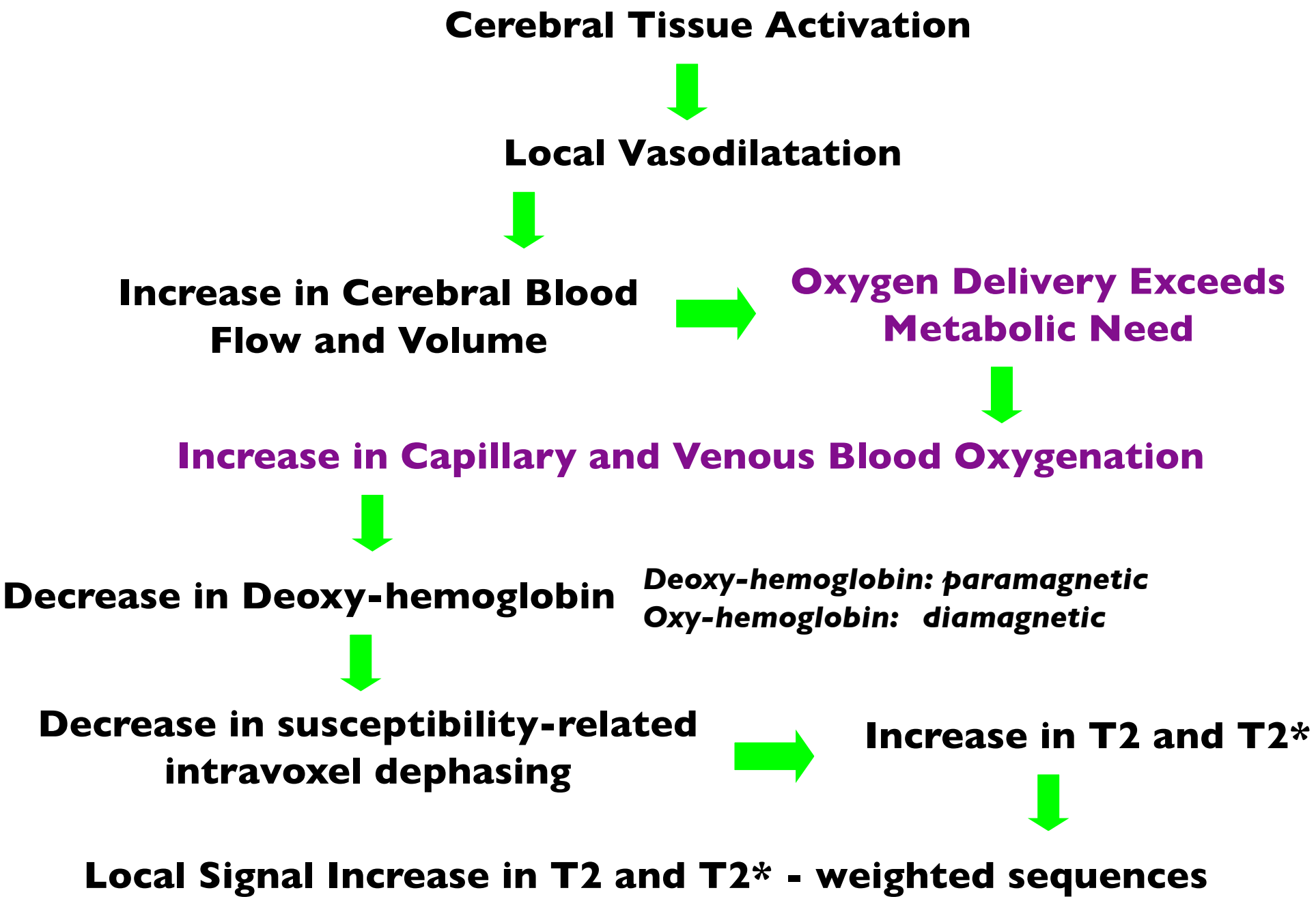
(positron emission tomography)

PETER T. FOX*†‡ AND MARCUS E. RAICHLE*†

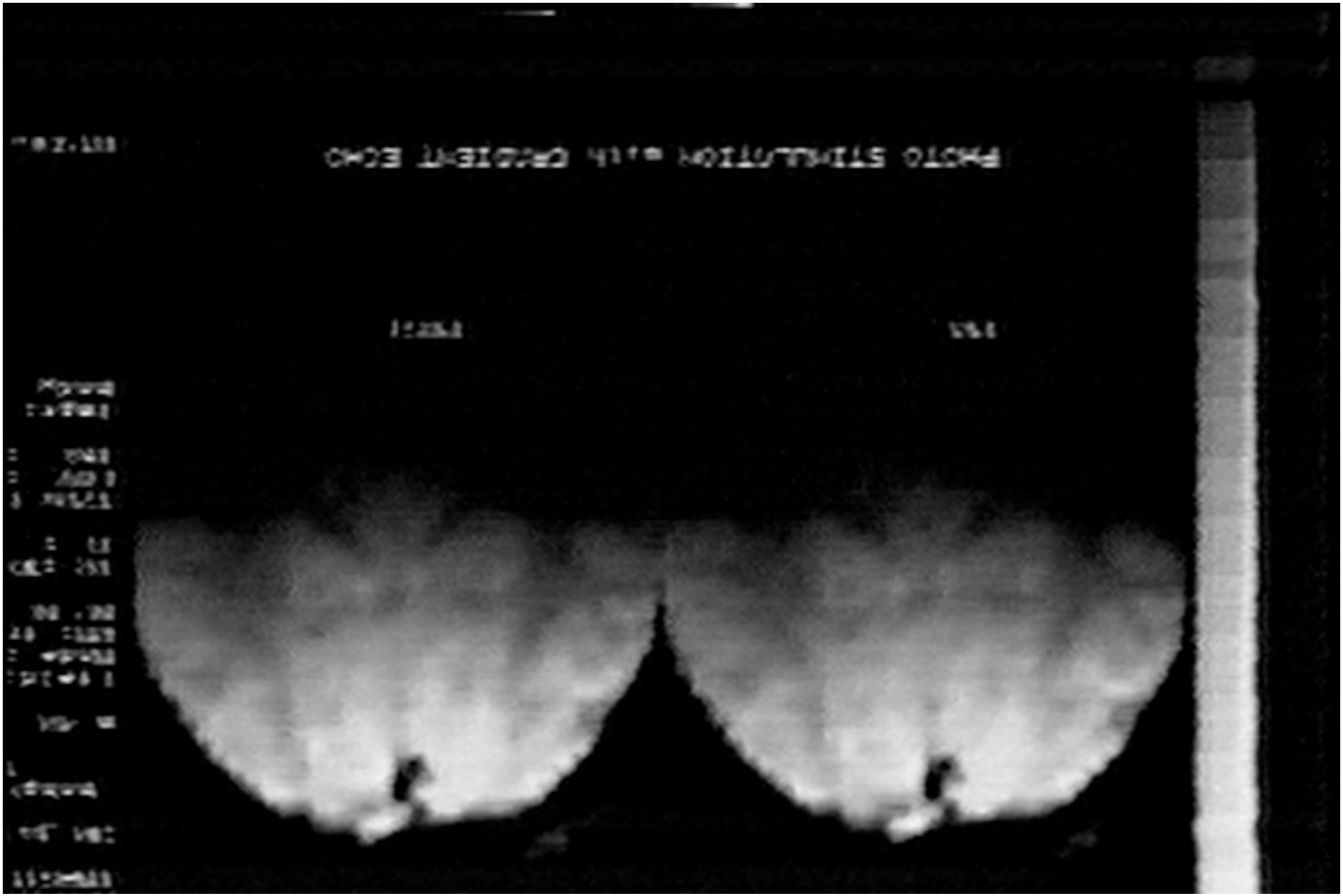
*Department of Neurology and Neurological Surgery (Neurology), †Department of Radiology (Radiation Sciences), and The McDonnell Center for Studies of Higher Brain Function, Washington University School of Medicine, St. Louis, MO 63110

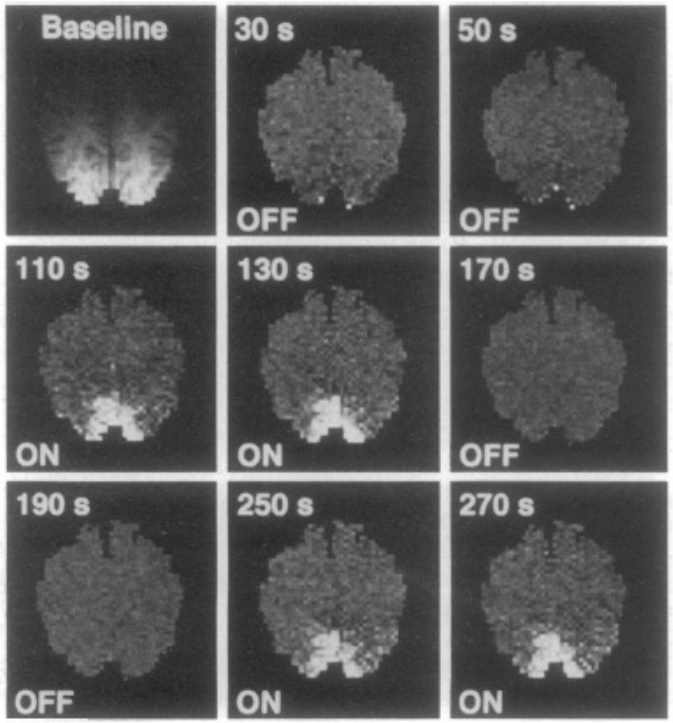
Communicated by Oliver H. Lowry, October 7, 1985

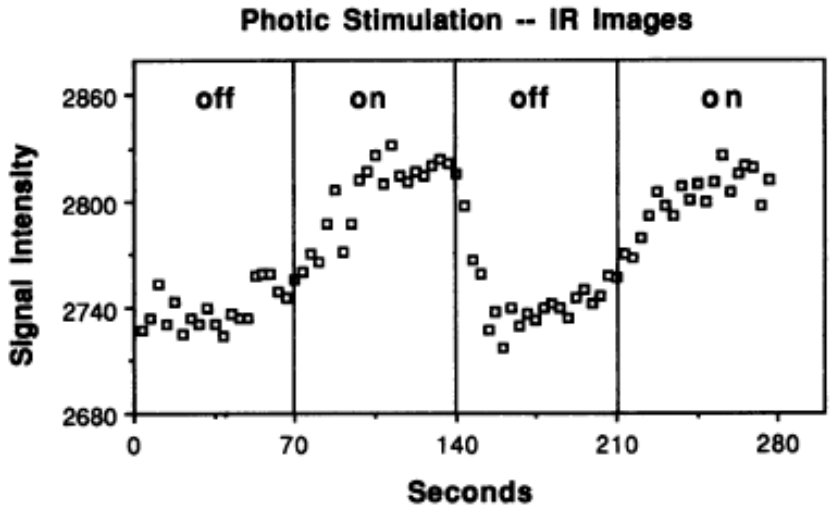
FIG. 1. Physiological uncoupling of brain blood flow and metabolism. (*Left*) Resting-state measurements. (*Right*) Stimulated-state measurements (unilateral vibrotactile stimulation of the fingers). All images are from a single subject's scanning session and pass through the same brain plane. Color scales are linear with the maxima set at a fixed multiple (1.6) of the global average, to facilitate visual comparisons (16). During specific somatosensory stimulation a marked focal increase in CBF (29% of mean, nine subjects, three trials per subject) was produced in the contralateral sensorimotor cortex. The observed increase in the $CMRO_2$ was much smaller (5% of mean, nine subjects, three trials per subject) and failed to attain significance. This physiological uncoupling of CBF and $CMRO_2$ flow produced a highly significant decrease in the local OEF (−19% of mean), indicating that tissue Po_2 (and probably pH) rose during stimulation. Note that, although the data were analyzed as contralateral/ipsilateral ratios (see text and Tables 1–4), the disparity between blood flow and metabolism was evident from the raw data and was not dependent on a particular strategy of analysis.

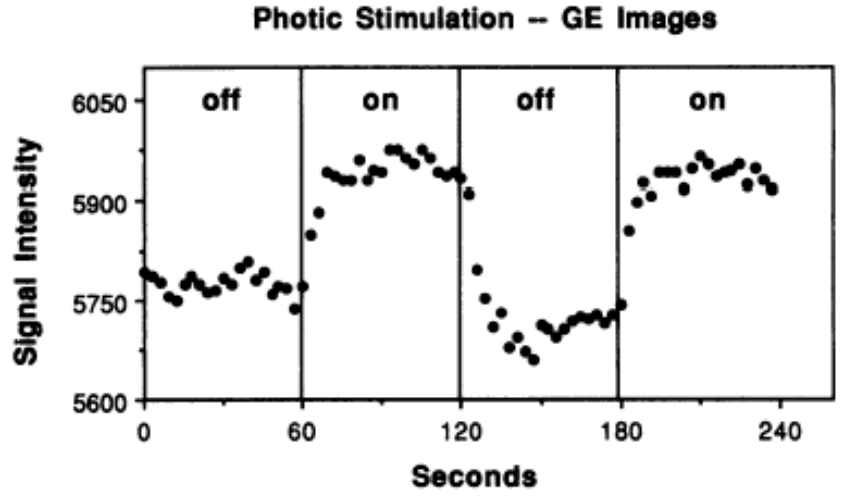

Cerebral Tissue Activation
Local Vasodilatation
Increase in Cerebral Blood Flow and Volume
Oxygen Delivery Exceeds Metabolic Need
Increase in Capillary and Venous Blood Oxygenation
Decrease in Deoxy-hemoglobin
Deoxy-hemoglobin: paramagnetic
Oxy-hemoglobin: diamagnetic
Decrease in susceptibility-related intravoxel dephasing
Increase in T2 and T2*
Local Signal Increase in T2 and T2* - weighted sequences

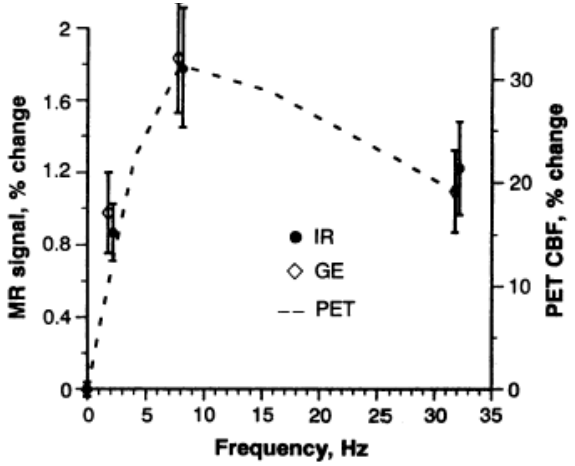
The video that started it all.
Aug 12, 1991: Tom Brady Plenary Lecture at SMRM, San Francisco











K. K. Kwong, et al, (1992) "Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation." **Proc. Natl. Acad. Sci. USA. 89, 5675-5679.**

photo sti. 5inGP

~~GM~~
IR

GE 350
70 sec plain
disdaq = 2 [30 pre] 40 post

[2.5]

IR
disdaq = 2 3.0 [TR] TI = 1.05 s.
40 pre 40 post

[50] 80

(20) ([30]) 20

90 sec 80
(40) (40)

20 20 20

10 cm. slice cardiac

removing spikes
irstim.pre 2 3 5-8 13 14 16 18 19 25-29 (16 together)
irstim.pos 34-38 40-47 49-65 67-80 (44 together)
Avg them (with seavg x5lv)
set mirstim.avg (save them)

10 cm. slice cardiac
TR = 2.5 s TE = 40
GE TA = 109
RA = 350
7106

MAY 9, 91

Michelle

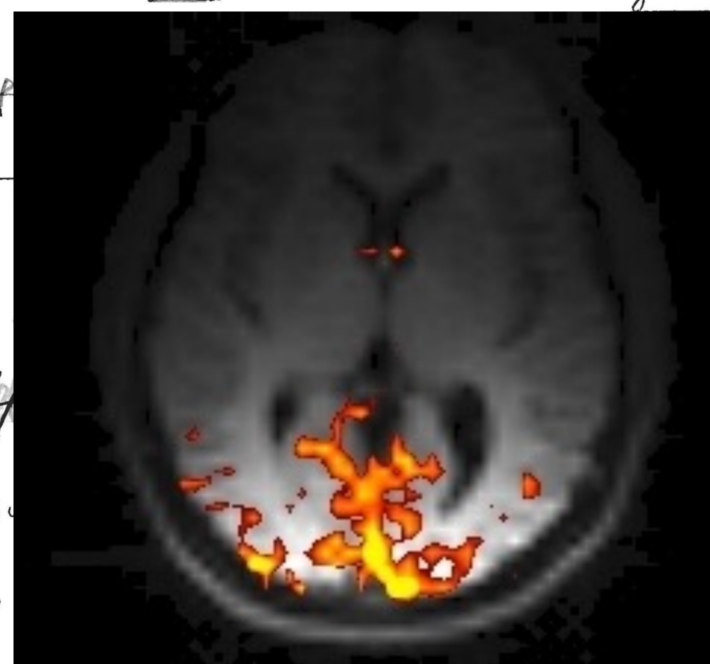
30 TI 40 on
GEstim. dat
gestim.pre 3-30 (28)
gestim.poo 33-70 (38) 3.0 (3.000) (2.3)
~~gest~~ gepre.avg
gepos.avg
7106
gestim.avg
gstim.sub 2.8
+7000

IR RA 370 TA 102

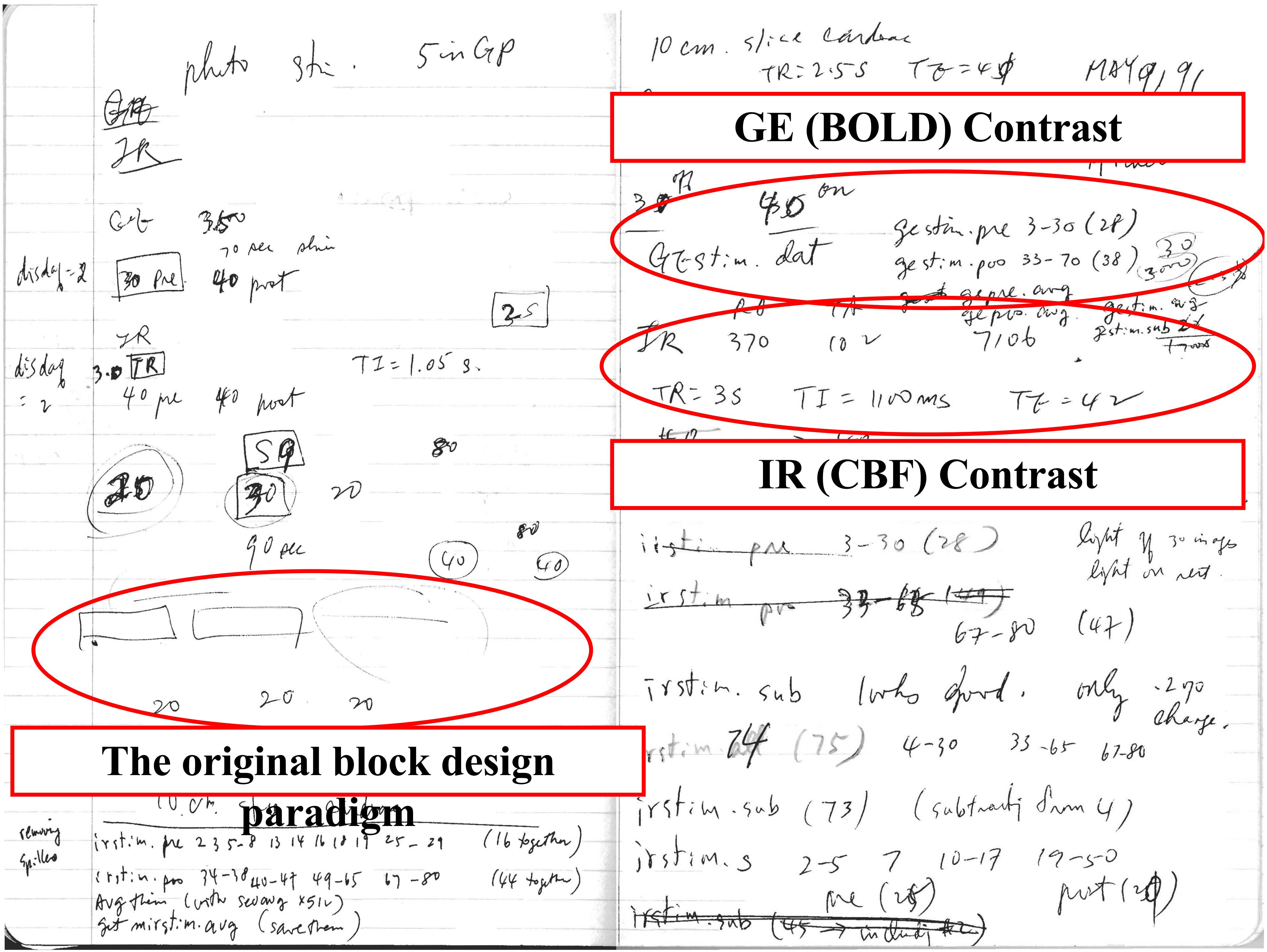
TR = 3s TI = 1100 ms TE = 42
~~40~~ → 40
30 50

IR Image 66
jump up.

~~irstim p~~
irstim
irstim.
irstim 74
irstim.s
irstim.s

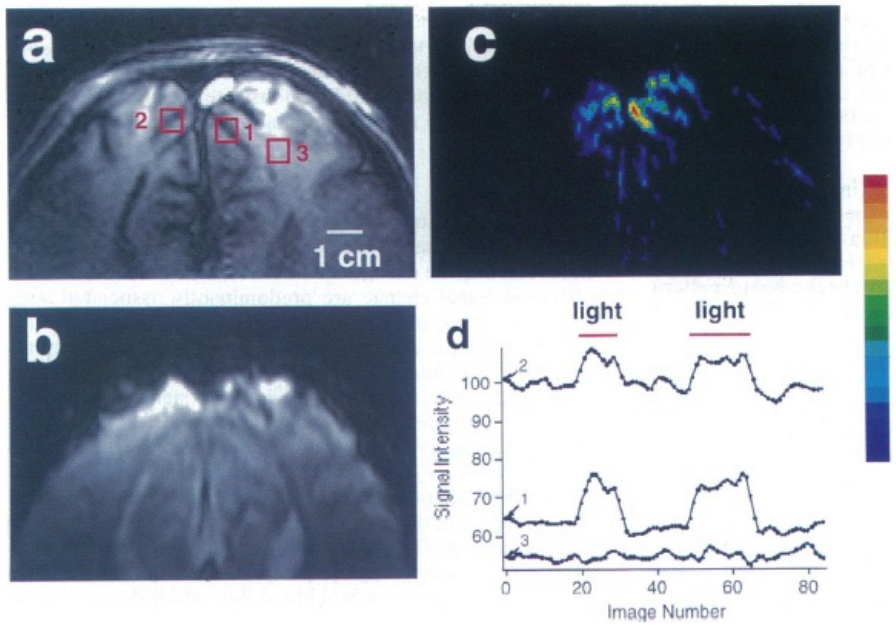


~~irstim.sub (45 → including #2)~~

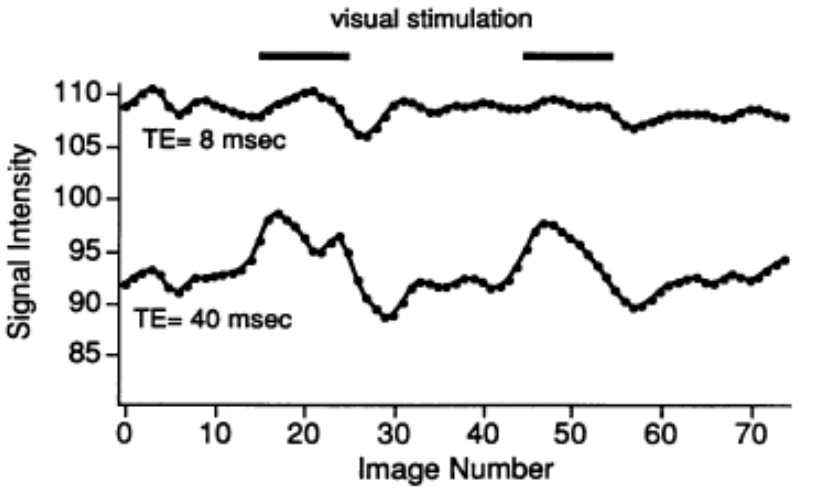


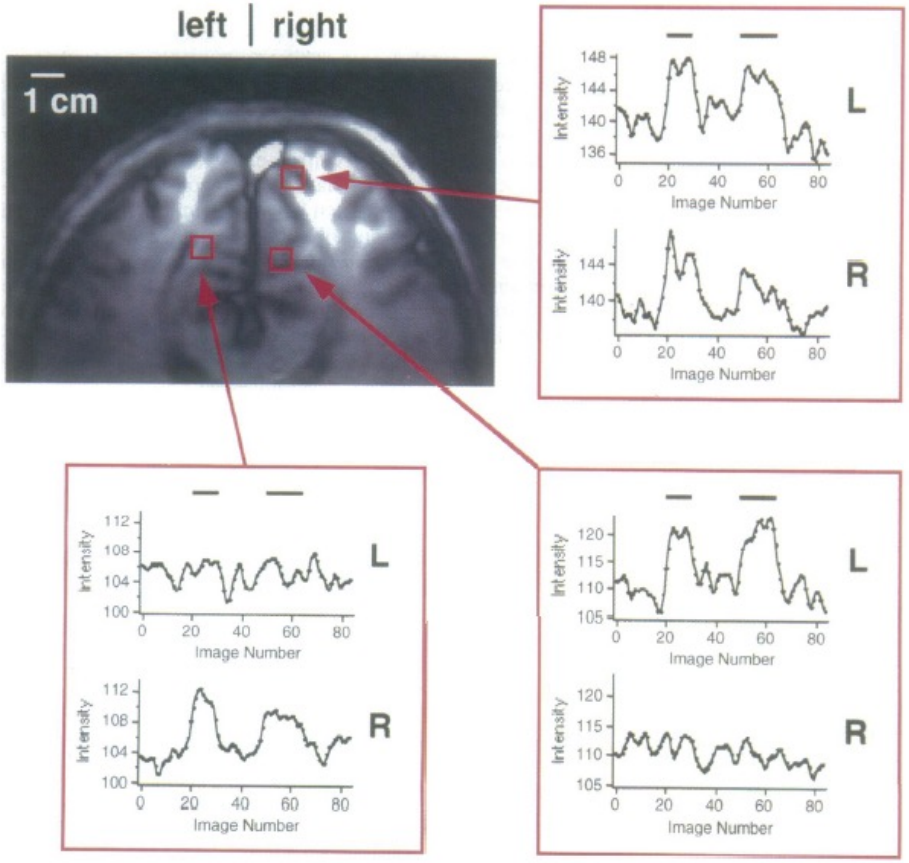
GE (BOLD) Contrast
IR (CBF) Contrast
The original block design paradigm
MAY 9, 91
TR = 3S TI = 1100ms TE = 42

Multi-shot results at 4T, U. Minnesota.

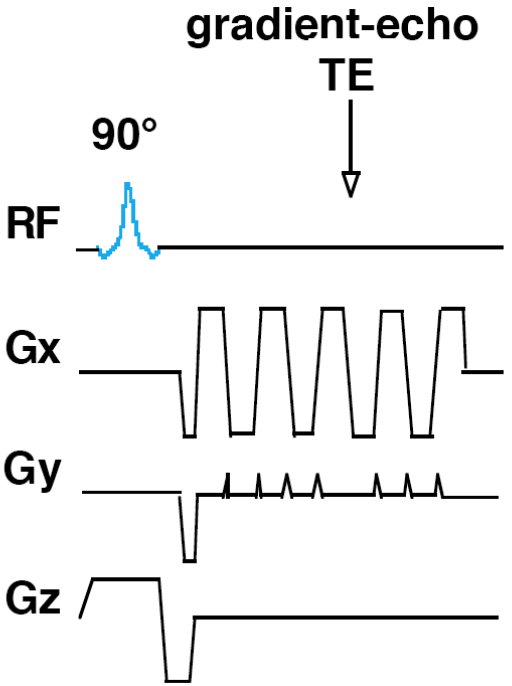


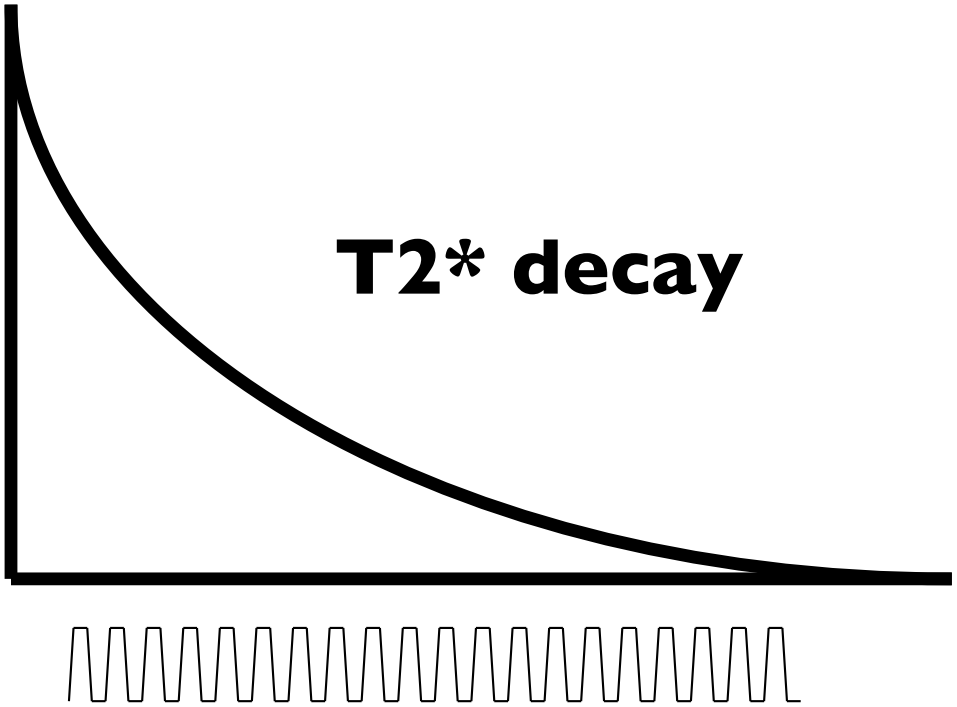
S. Ogawa, et al., (1992) "Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging." Proc. Natl. Acad. Sci. USA. 89, 5951-5955.





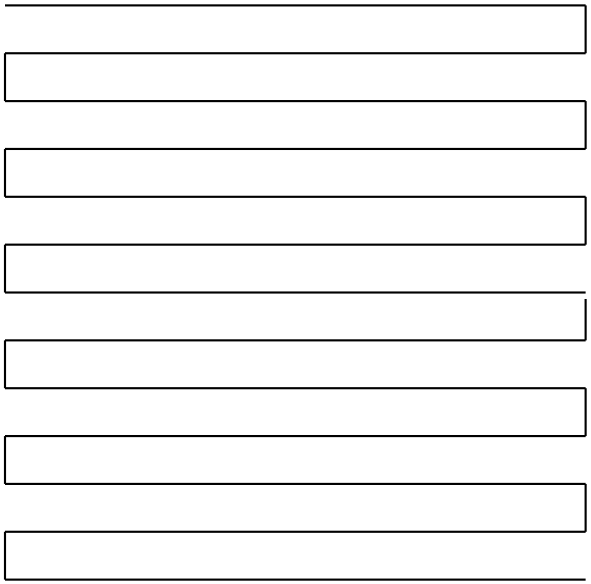
Single Shot Echo Planar Imaging (EPI)





EPI Readout Window

≈ 20 to 40 ms



What preceded the results from the Medical College of Wisconsin…

MAGNETIC RESONANCE IN MEDICINE 21, 39–48 (1991)

Coil Optimization for MRI by Conjugate Gradient Descent

ERIC C. WONG,* A. JESMANOWICZ, AND JAMES S. HYDE

Biophysics Section, Department of Radiology, Medical College of Wisconsin, Milwaukee, Wisconsin 53226

Received April 30, 1990; revised June 29, 1990

Local head gradient coils: Window(s) of opportunity

Eric C. Wong

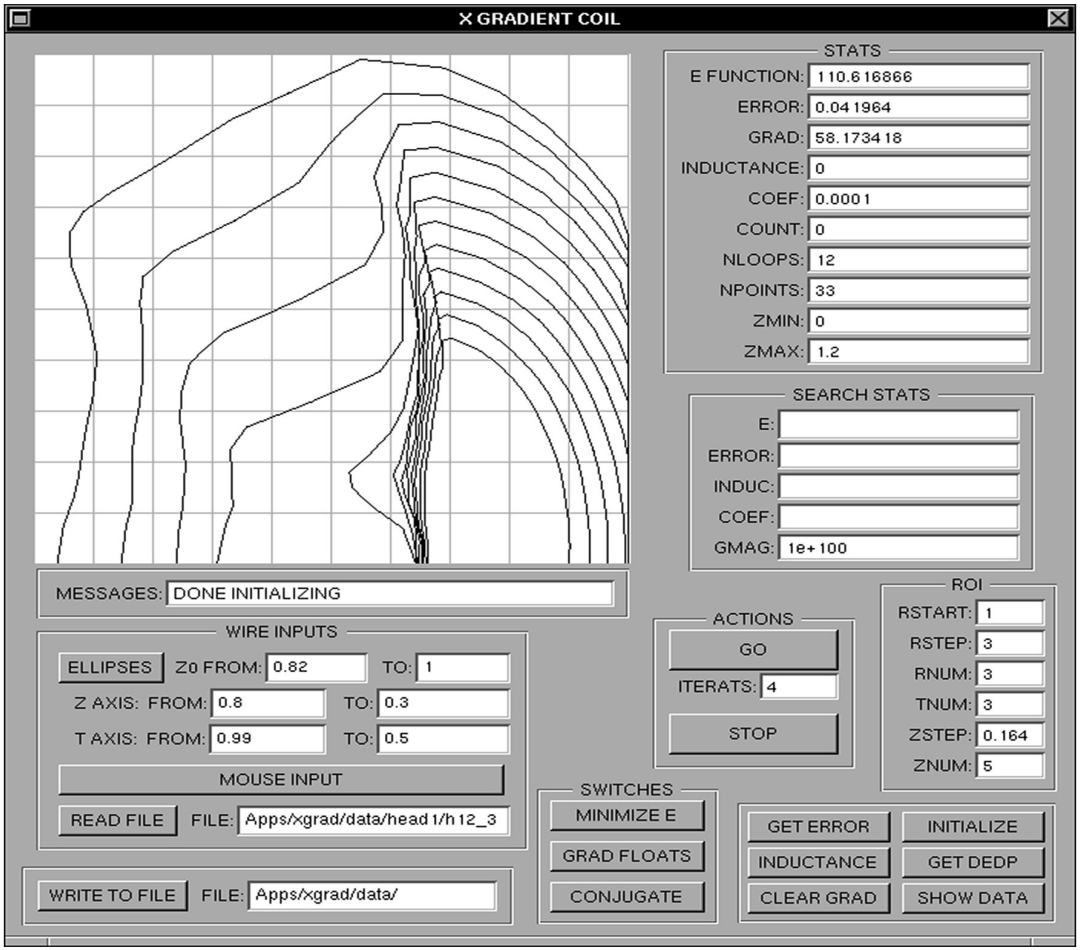
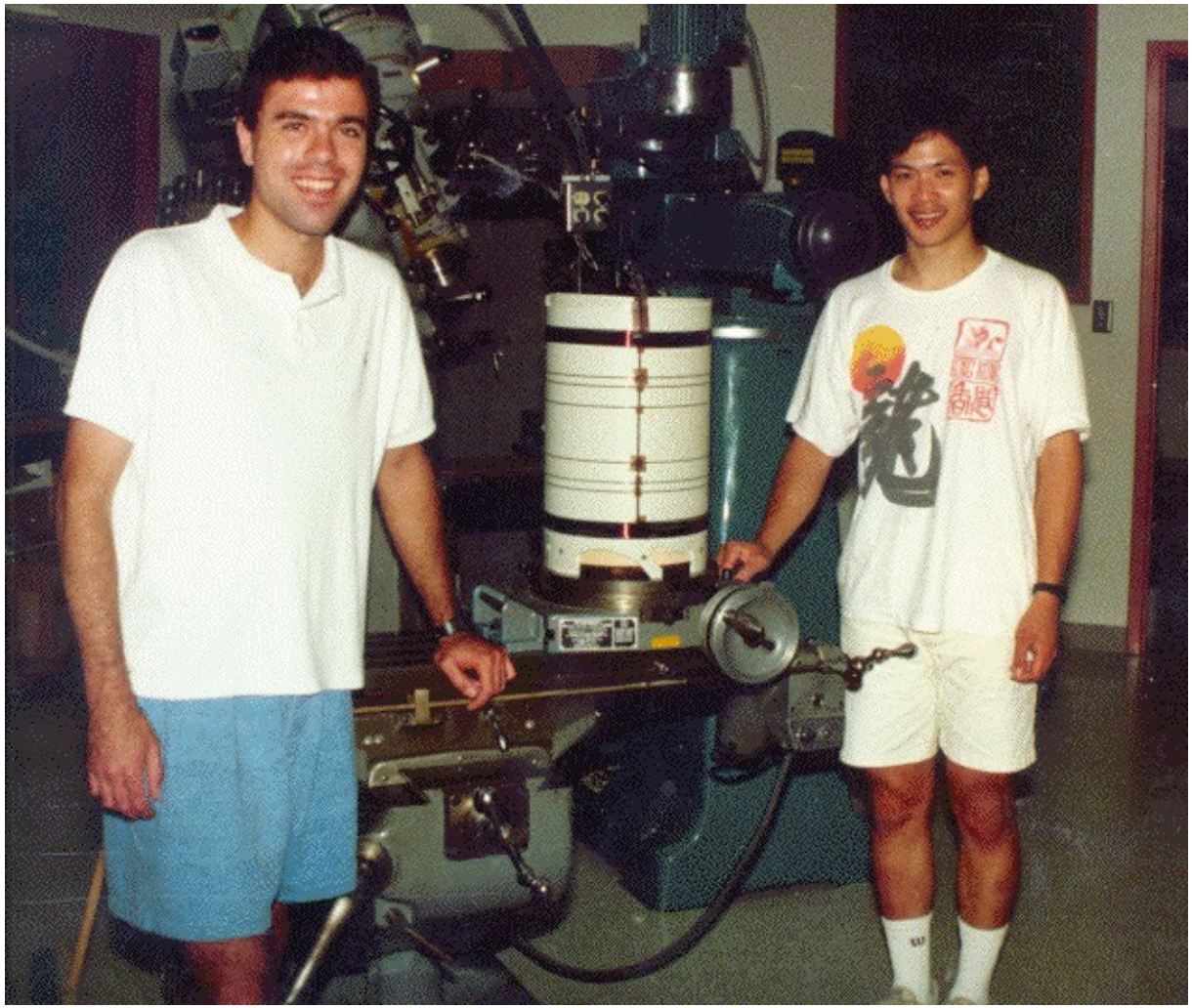


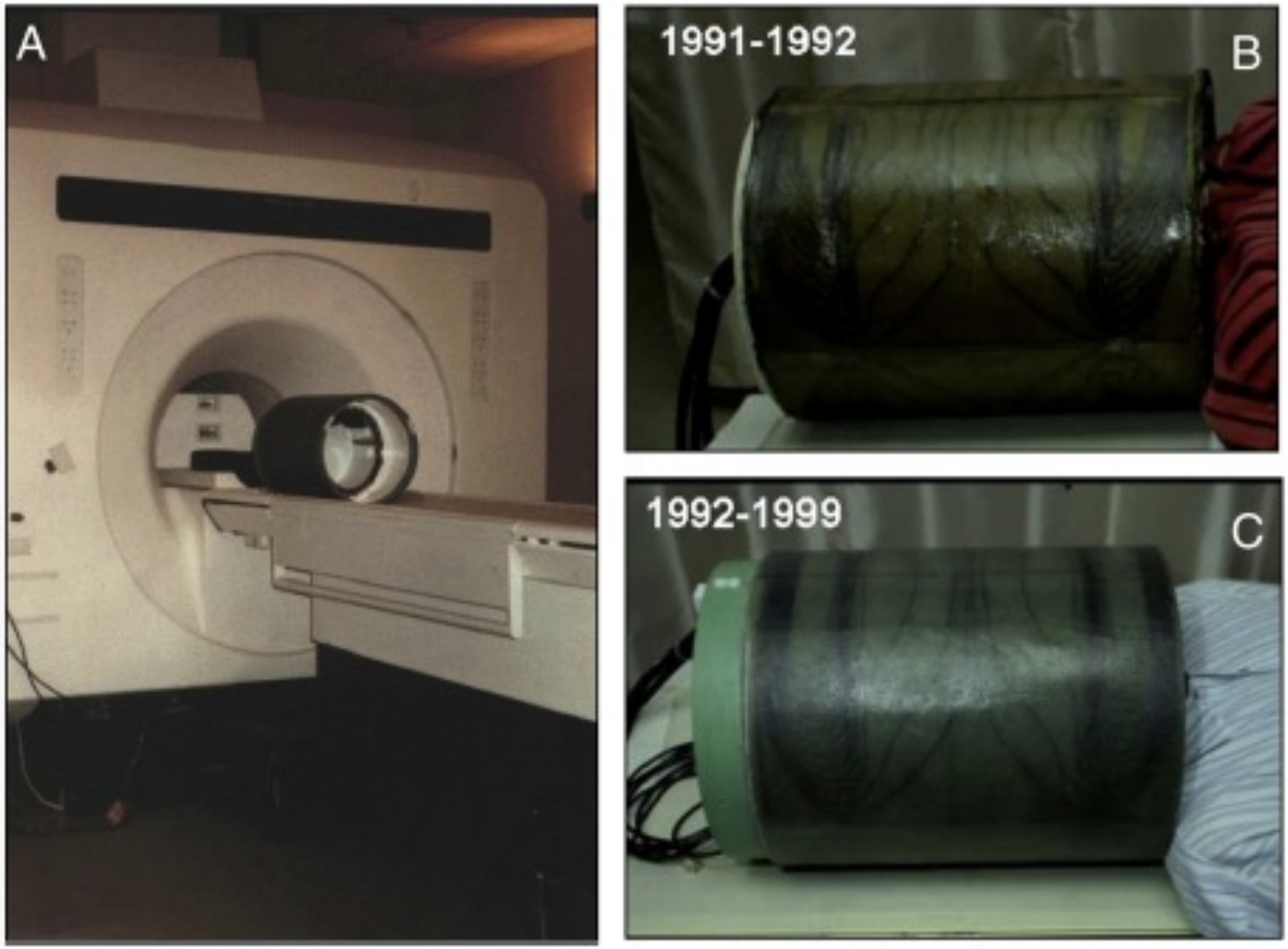
Fig. 1 GUI for gradient descent gradient coil design tool. The design shown is one octant of the X gradient coil designed and built in August 1991. The program was written in Objective C and ran on a NeXT Cube computer.

NeuroImage, Volume 62, Issue 2, 2012, 660 - 664

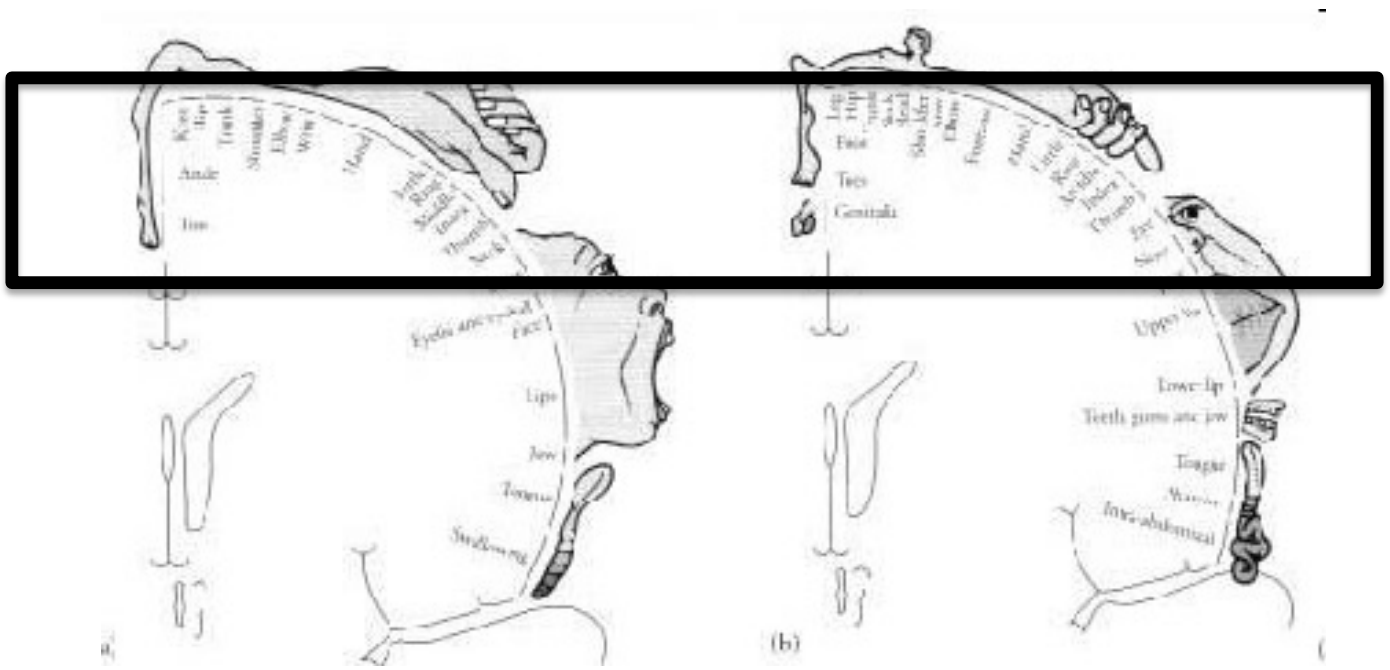
http://dx.doi.org/10.1016/j.neuroimage.2012.01.025



August, 1991


A
1991-1992
B
1992-1999
C

Initially could only do one slice…



2.5 cm !

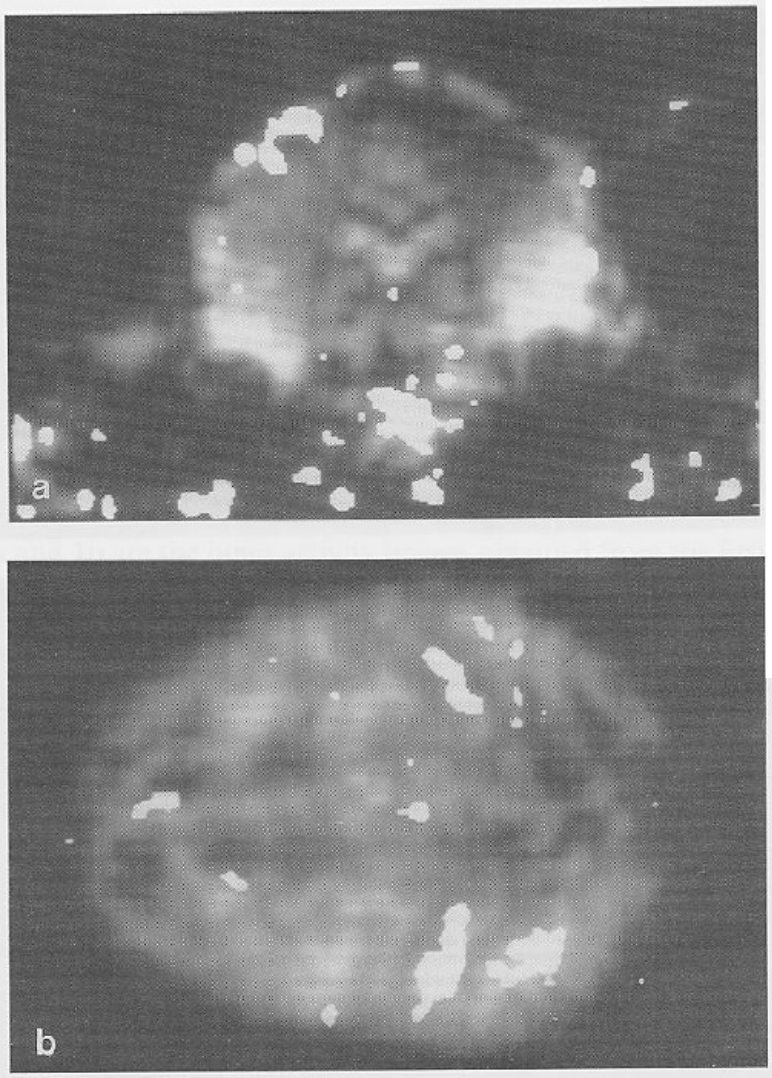
TR = 2 sec
TE = 50 ms
One slice
In plane 3.75 x 3.75

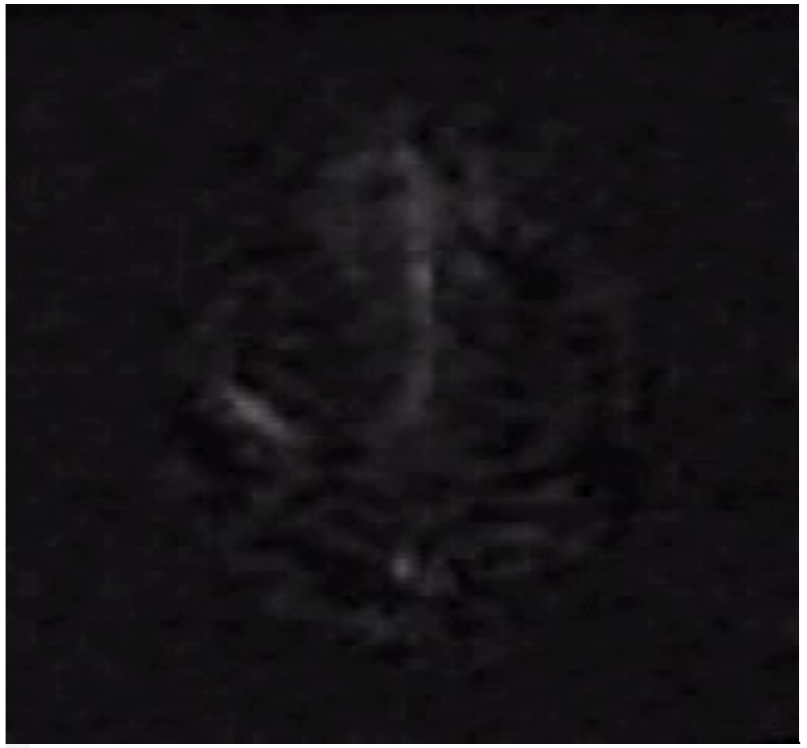
One little known fact…

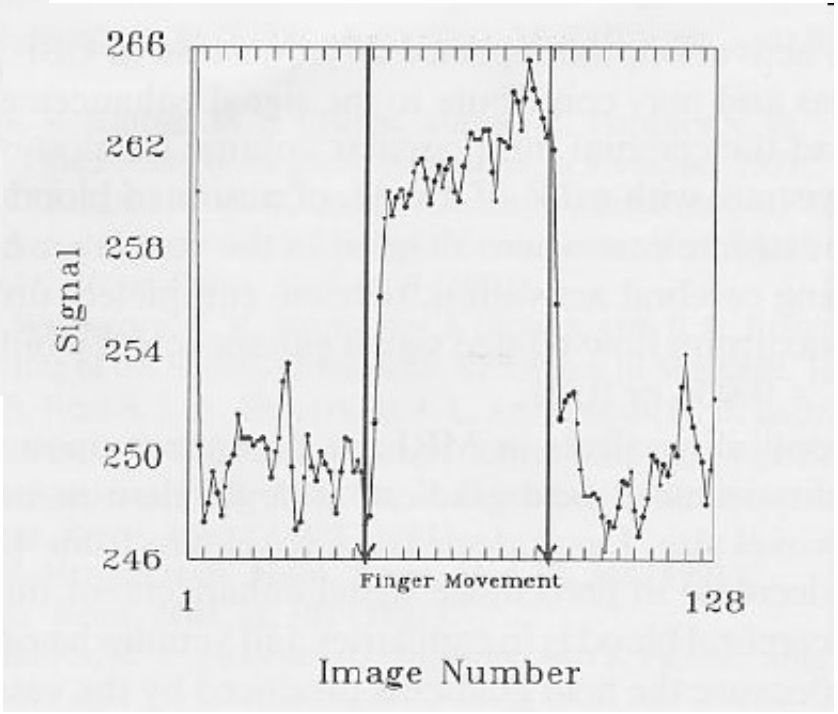
We didn't even need a gradient coil:

EPI at 5mm x 5mm x 5mm was quite possible using 100 amp gradient amplifiers and the whole body gradient coils…

Every scanner in the world in 1991 could have performed EPI-based fMRI at perfectly reasonable resolution.



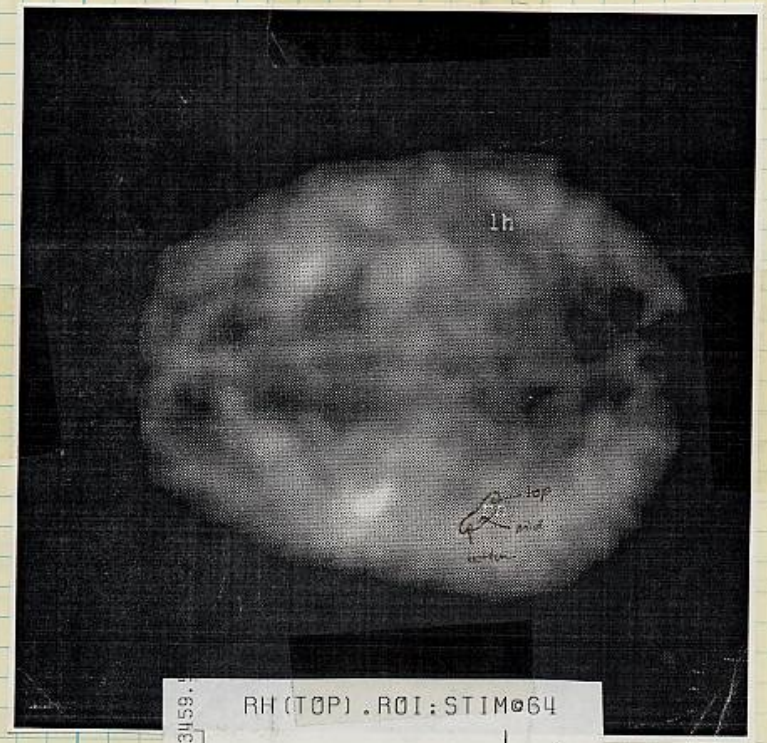


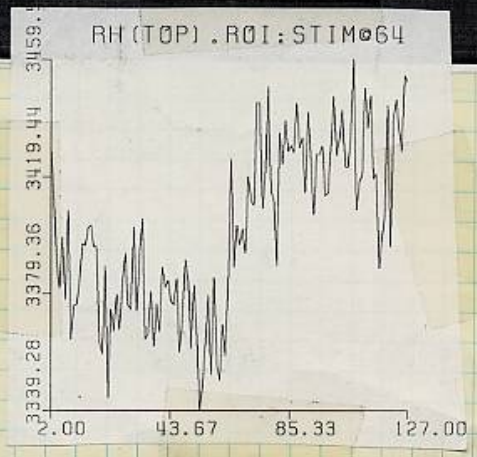


P. A. Bandettini, et al., (1992)
"Time course EPI of human brain function during task activation."
Magn. Reson. Med 25, 390-397.

9-16-91 Results from dH61 (Sig ↑ upon stim?!!)

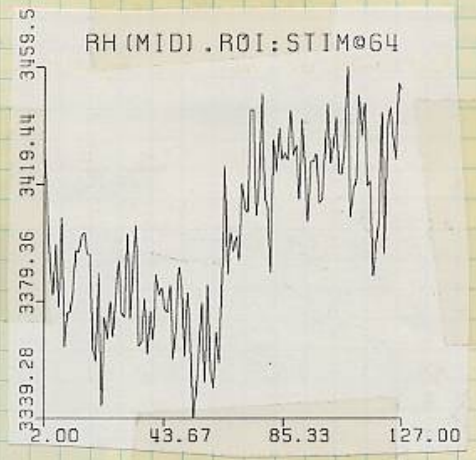
Experiment 1: Rest until G3 then move right fingers



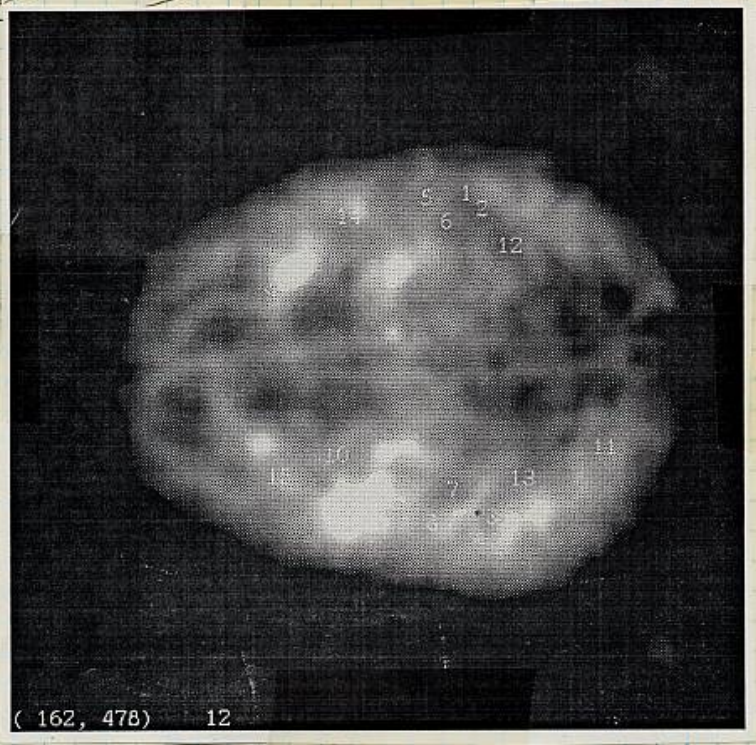


19

9-16-91



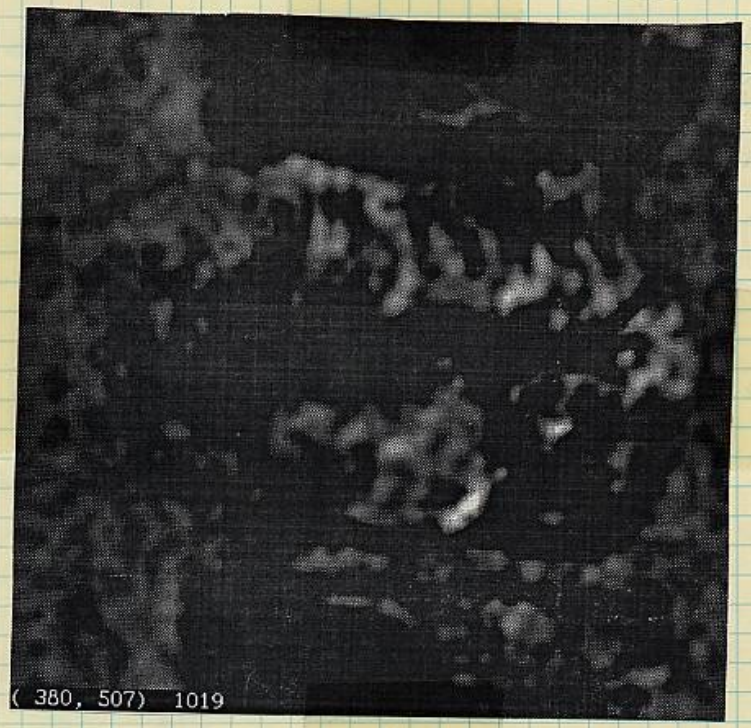
ROI's from p17



9-16-91

Finally, a difference image in which the average of the first 64 images (no movement) is subtracted from the last 64 images (movement) of right hand.

Right-Hand Movement



Resolution.
20 cm / 64
.3125 cm
= 3.125 mm

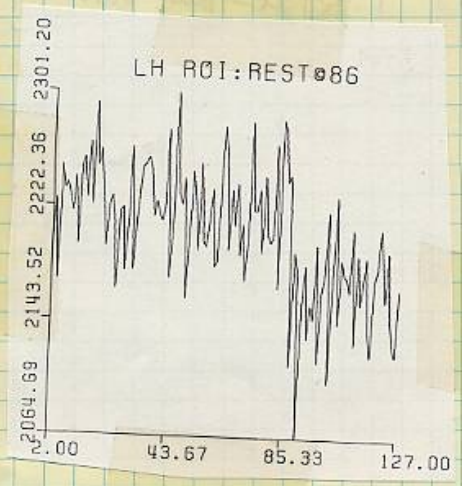
Brightest area is an indicator of largest signal increase when the right hand was stimulated (fingers moved) → exactly corresponds to region of motor cortex and sensory and supplimentary motor cortex as well that is associated with right hand movement

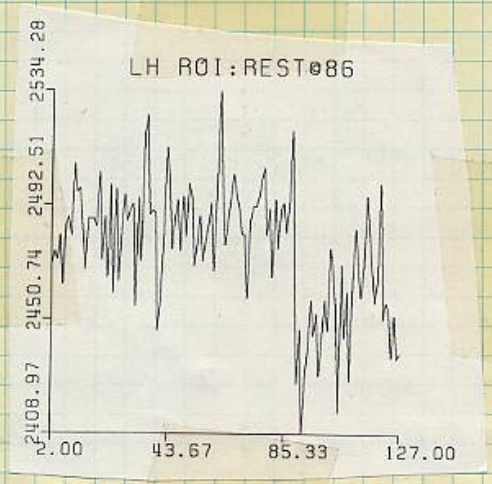
9-16-91

Results from experiment #2

Experiment #2 consisted of moving the left hand and then stopping the movement after 86 images.

LH ROI from p16





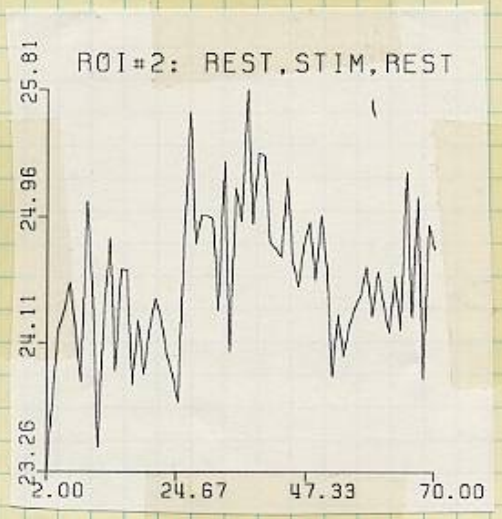
Trying to figure out the basic mechanism.

24

9-16-91

Experiment #3

Rest for 24 images, Move both hands for 24, then rest For 24.

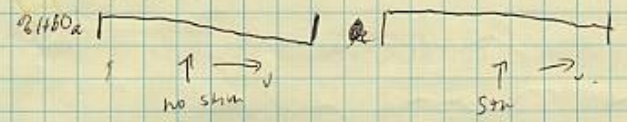


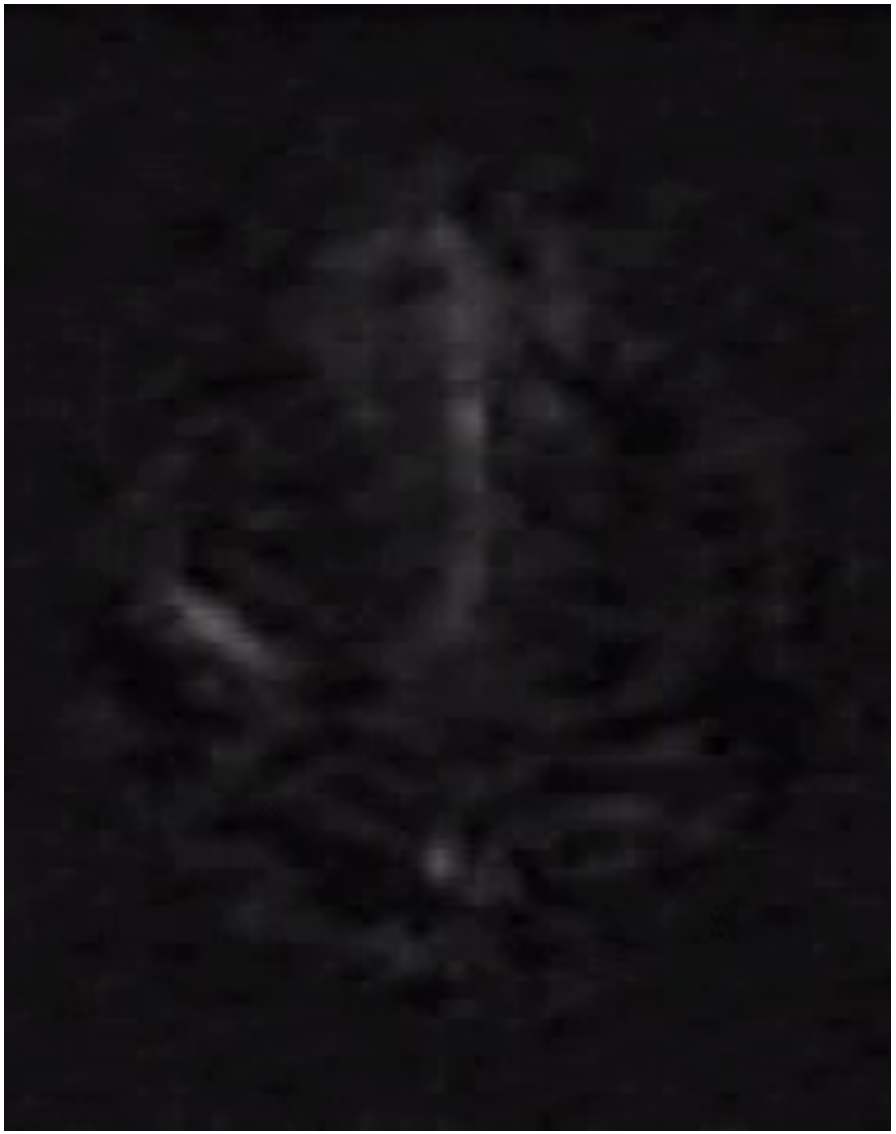
Rough Theory of What is going on here:

Stim nerve → move hand → ↑CO_2 ↑HT ↓O_2 in tissue → capillary and vein dilation → ↑ Blood flow → ↓% deoxy at stim

↑ signal due to ↓ susceptibility ← Stop stim ← ↑O_2 ↓CO_2 ↓HT in tissue ← vasoconstriction + Cap. ← decreased blood flow ← ↑% deoxyHb at steady state

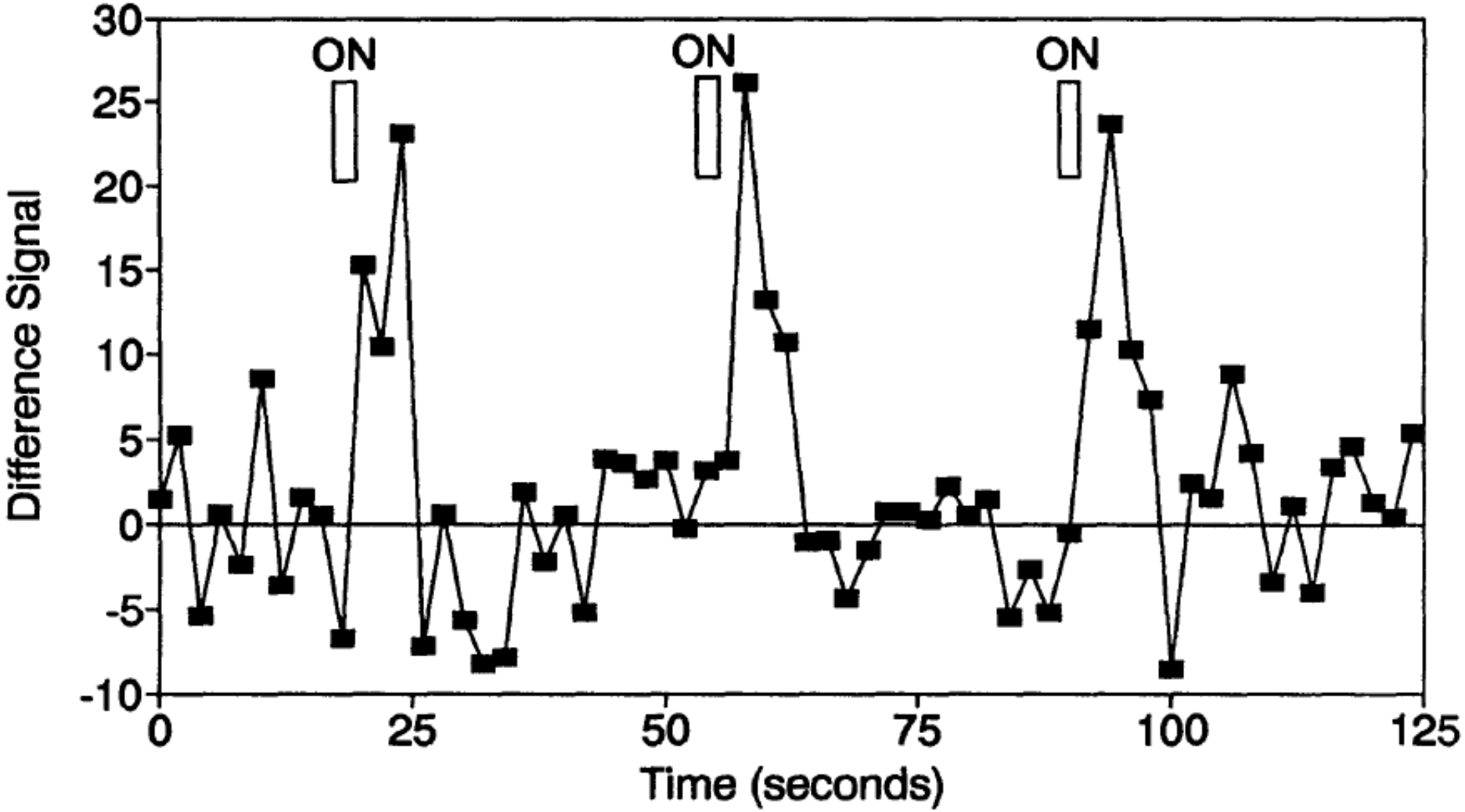
Question: Relationship between flow volume and bulk susceptability in capillaries.





1991

The first event-related studies.



Blamire, A. M., et al. (1992). "Dynamic mapping of the human visual cortex by high-speed magnetic resonance imaging." Proc. Natl. Acad. Sci. USA 89: 11069-11073.

1992…Perfusion using Arterial Spin Labeling

MAGNETIC RESONANCE IN MEDICINE 23, 37–45 (1992)

Perfusion Imaging

JOHN A. DETRE,*·† JOHN S. LEIGH,* DONALD S. WILLIAMS,‡ AND ALAN P. KORETSKY‡·§

*Metabolic Magnetic Resonance Research Center and Department of Biochemistry and Biophysics, University of Pennsylvania School of Medicine, Philadelphia, Pennsylvania 19104; and ‡Pittsburgh NMR Center for Biomedical Research and §Department of Biological Sciences, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213

Received July 2, 1990; revised January 3, 1991

Measurement of tissue perfusion is important for the functional assessment of organs *in vivo*. Here we report the use of ^{1}H NMR imaging to generate perfusion maps in the rat brain at 4.7 T. Blood water flowing to the brain is saturated in the neck region with a slice-selective saturation imaging sequence, creating an endogenous tracer in the form of proximally saturated spins. Because proton T_1 times are relatively long, particularly at high field strengths, saturated spins exchange with bulk water in the brain and a steady state is created where the regional concentration of saturated spins is determined by the regional blood flow and regional T_1. Distal saturation applied equidistantly outside the brain serves as a control for effects of the saturation pulses. Average cerebral blood flow in normocapnic rat brain under halothane anesthesia was determined to be 105 ± 16 cc · 100 g^{-1} · min^{-1} (mean ± SEM, $n = 3$), in good agreement with values reported in the literature, and was sensitive to increases in arterial pCO_2. This technique allows regional perfusion maps to be measured noninvasively, with the resolution of ^{1}H MRI, and should be readily applicable to human studies.

1992…Perfusion using Arterial Spin Labeling

Proc. Natl. Acad. Sci. USA
Vol. 89, pp. 212–216, January 1992
Biophysics

Magnetic resonance imaging of perfusion using spin inversion of arterial water

(cerebral blood flow/adiabatic fast passage/hypercarbia/rat brain/cold injury)

DONALD S. WILLIAMS*, JOHN A. DETRE†‡, JOHN S. LEIGH†, AND ALAN P. KORETSKY*§

*Pittsburgh Nuclear Magnetic Resonance Center for Biomedical Research, and §Department of Biological Sciences, Carnegie Mellon University, Pittsburgh, PA 15213; and †Metabolic Magnetic Resonance Research Center, Department of Radiology, and ‡Department of Neurology, University of Pennsylvania School of Medicine, Philadelphia, PA 19104

Communicated by Mildred Cohn, September 19, 1991

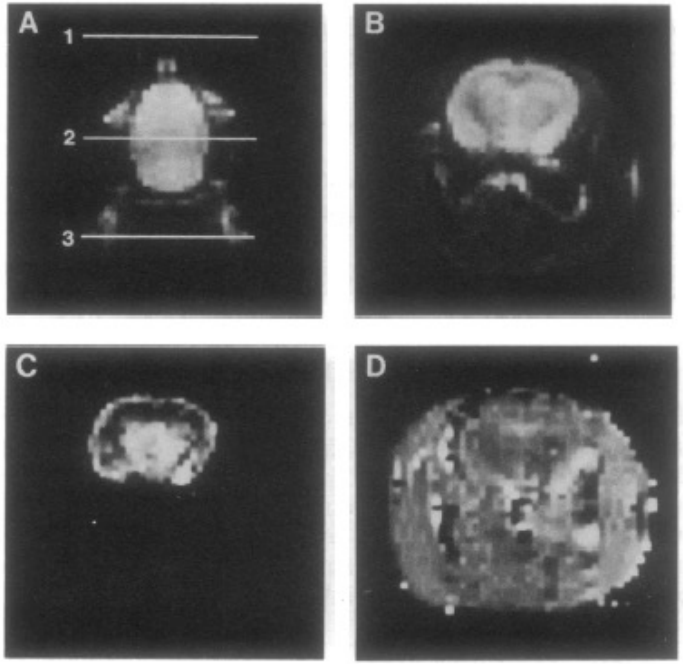


FIG. 2. (*A*) Coronal image of a rat head. The resonance planes for radiofrequency used for spin inversion by AFP for control and inversion images are indicated by 1 and 3, respectively, and plane 2 is the detection plane. (*B*) Control transverse image from the detection plane (plane 2 in *A*). (*C*) Difference image between control and inversion images. (*D*) T_{1app} image.

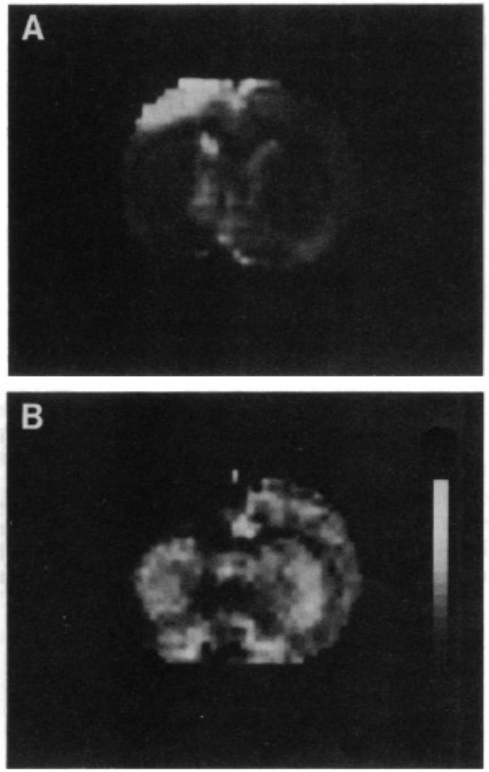
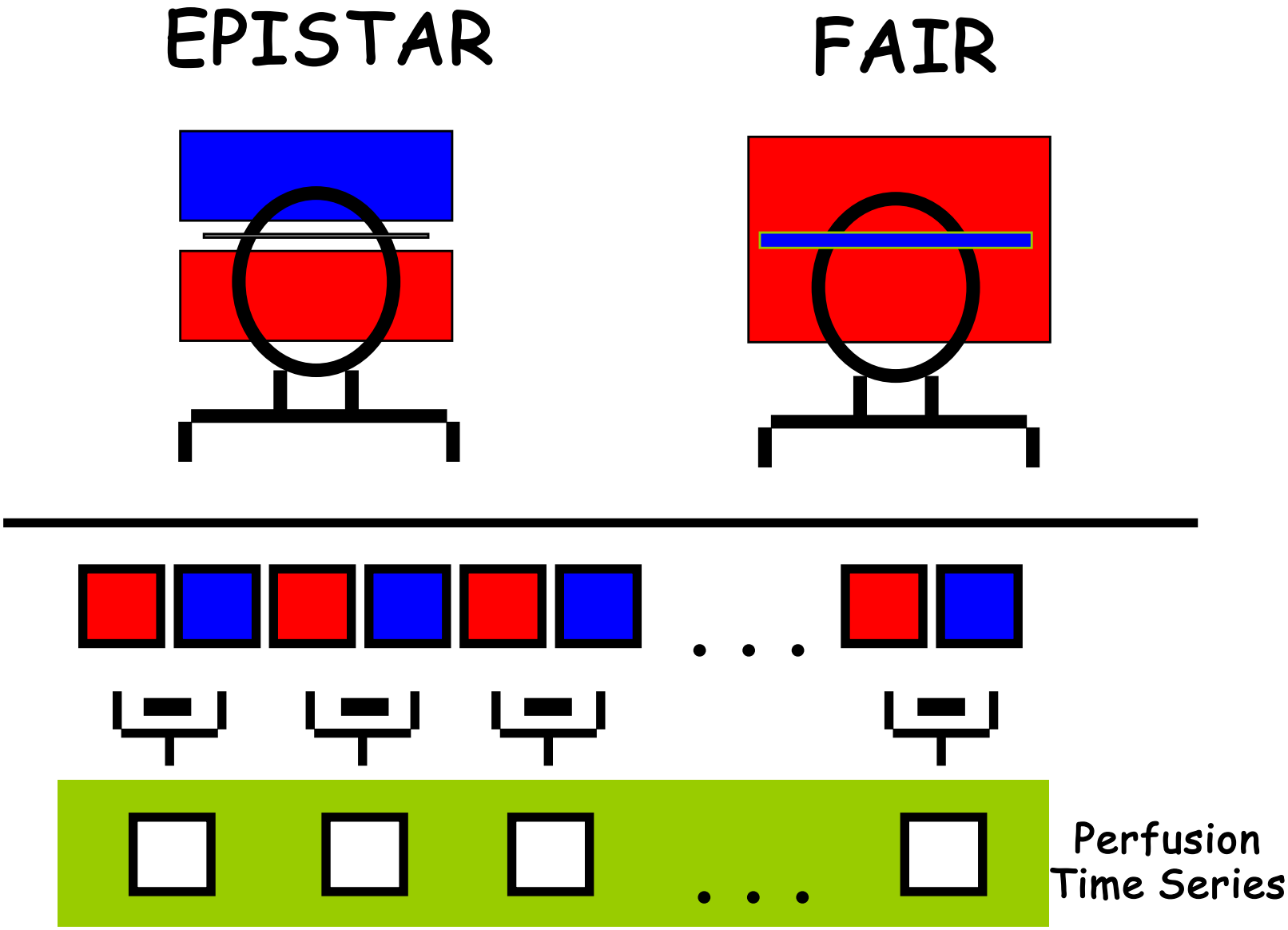
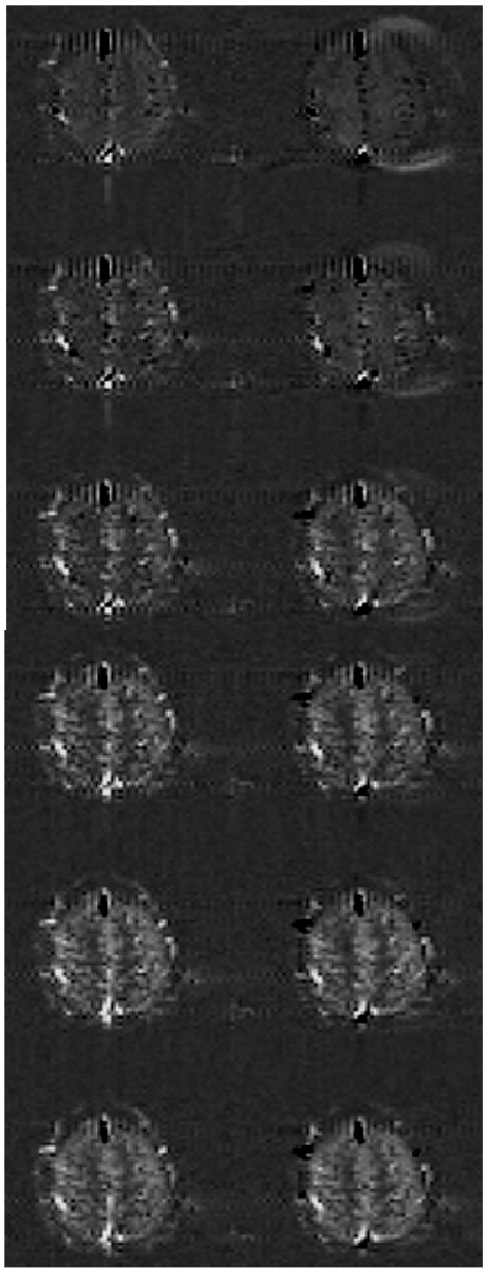


FIG. 5. Comparison of conventional MRI and perfusion imaging of a rat brain subjected to a regional cold injury. (*A*) Conventional T_2-weighted image (TE = 60 ms, TR = 2 s). The injured region shows up as hyperintensity due to a longer T_2. (*B*) Perfusion image of the same slice. The grey scale is from 0 to 6 $ml \cdot g^{-1} \cdot min^{-1}$. The injured region is dark due to low flow.

Magnetic Resonance in Medicine
“30 papers that shaped the field.”

Perfusion Contrast



TI (ms)	FAIR	EPISTAR
200		
400		
600		
800		
1000		
1200		

- **K. K. Kwong, et al, (1992)** "Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation." **Proc. Natl. Acad. Sci. USA. 89, 5675-5679.**

- **S. Ogawa, et al., (1992)** "Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging." **Proc. Natl. Acad. Sci. USA. 89, 5951-5955.**

- **P. A. Bandettini, et al., (1992)** "Time course EPI of human brain function during task activation." **Magn. Reson. Med 25, 390-397.**

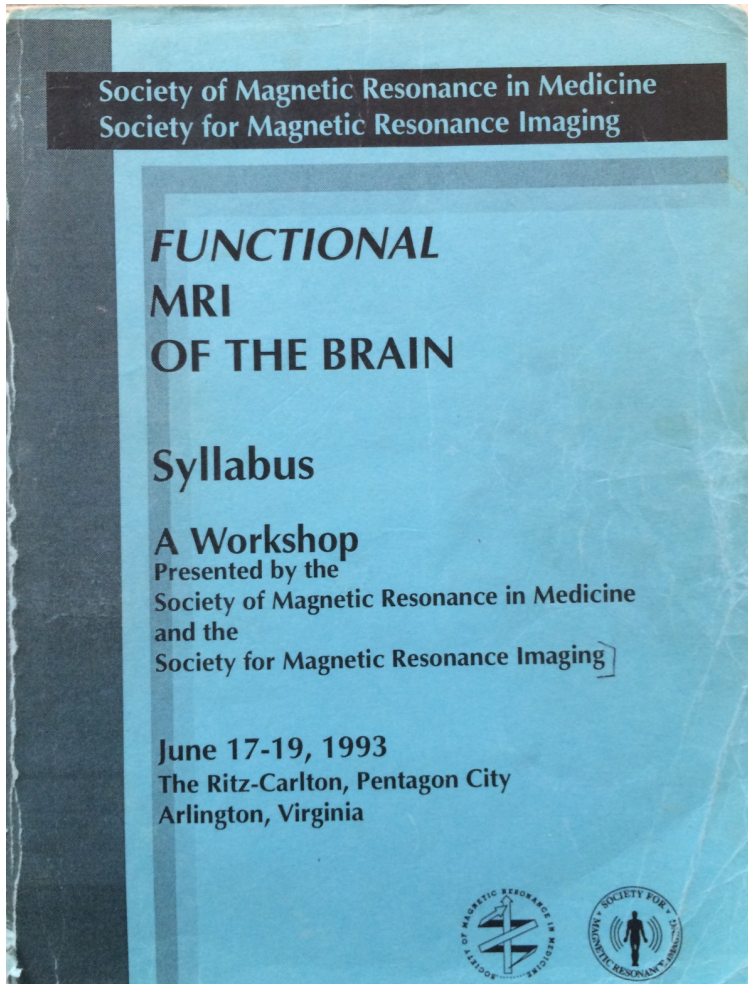
- **Blamire, A. M., et al. (1992).** "Dynamic mapping of the human visual cortex by high-speed magnetic resonance imaging." **Proc. Natl. Acad. Sci. USA 89: 11069-11073.**

- **Frahm, J., et al (1992)** "Dynamic MR Imaging of Human Brain Oxygenation During Rest and Photic-Stimulation." **Journal of Magnetic Resonance Imaging, 2, 501-505.**

Functional MRI of the Brain

A Report on the SMRM/SMRI Workshop held in Arlington, Virginia June 17–19, 1993

MRM 30:405–408 (1993)



Denis Le Bihan
National Institutes of Health
Diagnostic Radiology Department
Building 10, Room 1C-660
Bethesda, Maryland 20892

Robert Turner
National Institutes of Health
Laboratory of Cardiac Energetics
Building 10, Room B1D-161
Bethesda, Maryland 20892

Michael E. Moseley
Department of Radiology
Stanford University
Stanford, California 94305-5488

James S. Hyde
Biophysics Research Institute
Medical College of Wisconsin
8701 Waterton Plank Road
Milwaukee, Wisconsin 53226

A proposed acronym...

Functional Neuroimaging with EPI: Sequence Issues

Robert Turner, Peter Jezzard, #Lucie Hertz-Pannier, #Denis Le Bihan, *David Feinberg

Laboratory of Cardiac Energetics, National Heart, Lung, and Blood Institute, and #Diagnostic Radiology Department, Clinical Center, NIH, Bethesda, MD 20892
*Department of Radiology, NYU Medical Center, New York, NY

ABSTRACT

Freedom from motion artifact, comparatively good SNR, rapid multi-slice capability, and excellent time resolution make Echo-Planar Imaging an excellent choice for BOLD contrast MR functional neuroimaging. However, when the gradient echo version of EPI is used for this purpose, problems arise regarding image quality and interpretation. Large draining veins distant from active neural regions are the major confusing factor. At high enough static magnetic fields, spin-echo EPI can be used to obtain images showing local changes of blood oxygenation related to brain activation, in which draining veins have less effect. The idea MRFN equence will combine gradient-recalled echo and spin echo features, and thus will be some variant of GRASE (GRAdient echo and Spin Echo).

A proposed acronym...

The earliest successful magnetic resonance functional neuroimaging (MRFN) studies with BOLD contrast were made using a gradient-echo version of echo-planar imaging (EPI). The EPI technique, proposed by Mansfield in 1977 (4), allows the capture of a complete MR image in under 100 ms. Thus most motions in the body are frozen and motion artifact rarely appears. EPI relies on a very rapidly switched magnetic field gradient of large amplitude, and a fast data capture rate. Since these features were not considered necessary by most manufacturers of commercial MR systems until recently, the technique has been available only in a few pioneering laboratories. The technique normally uses a full 90 degree rf pulse for spin excitation, and hence provides a comparatively high single-shot signal/noise ratio (SNR), considering the large receiver bandwidth required. For brain imaging, with equal voxel size, an EPI image with 40 ms acquisition time has been found to have the same SNR as a FLASH image with optimized bandwidth taking 2 seconds to acquire. Faster FLASH images will have a poorer SNR than EPI. Low flip-angle variants of EPI (5) can of course provide much higher values of SNR/unit time, though this sacrifices SNR in each

Functional Mapping of the Human Visual Cortex at 4 and 1.5 Tesla Using Deoxygenation Contrast EPI

R. Turner, P. Jezzard, H. Wen, K. K. Kwong, D. Le Bihan, T. Zeffiro, R. S. Balaban

MRM 29:277–279 (1993)

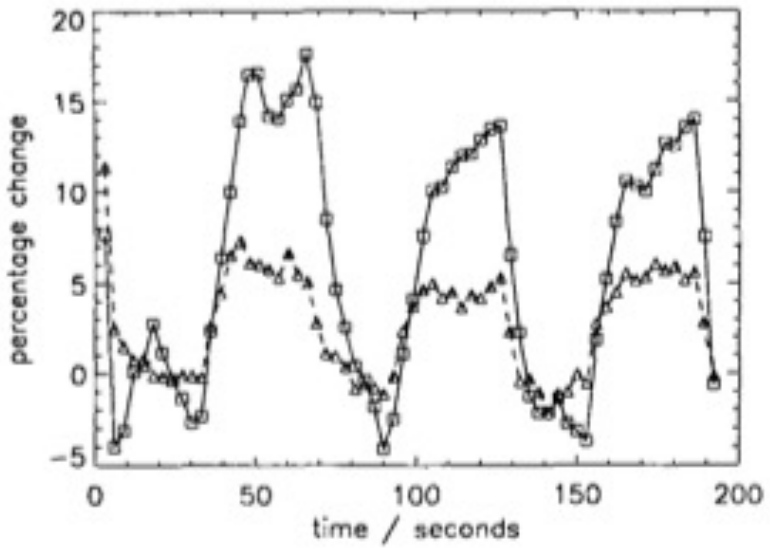
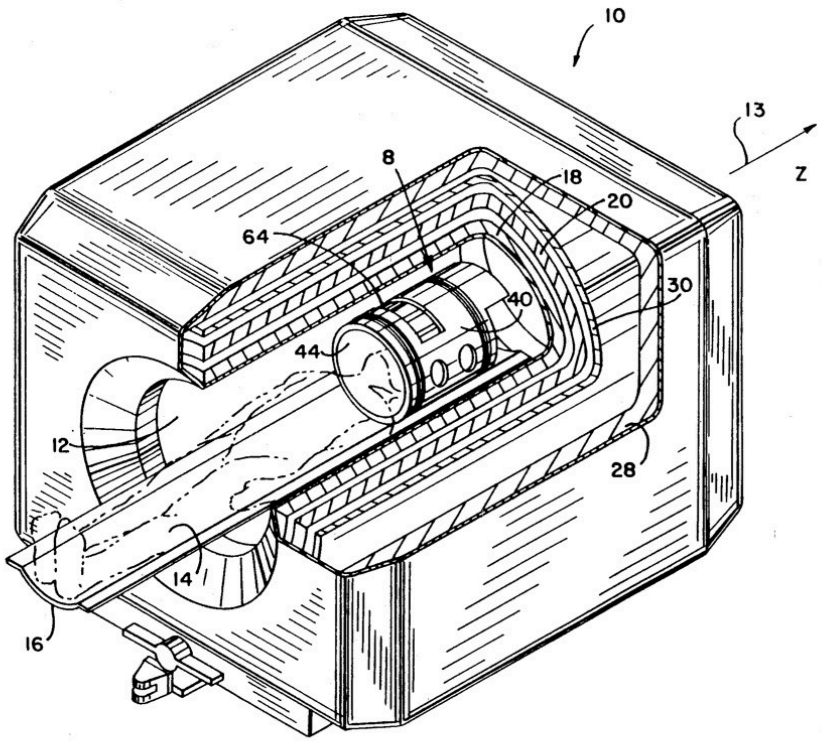


FIG. 2. Plot of fractional change in 4 T (squares) and 1.5 T (triangles) EPI image intensity versus time in the eight-voxel regions of interest in the visual cortex shown in Fig. 1, for a volunteer experiencing alternate 30-s periods of rest and photic stimulation. Details of acquisition for the 4 and 1.5 T data are described in the

Local Gradient Coil

FIG. 1



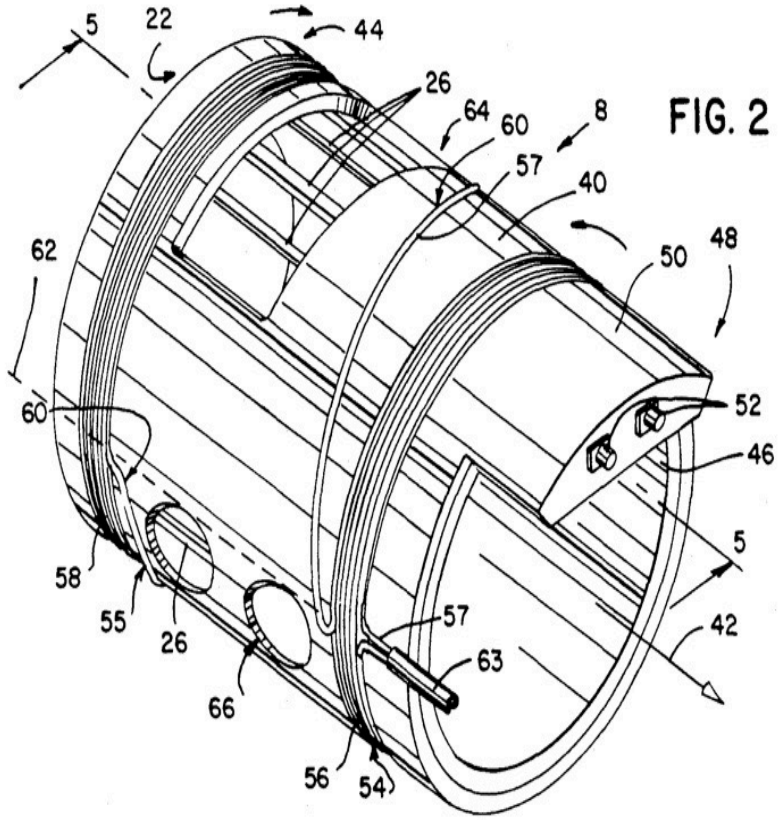
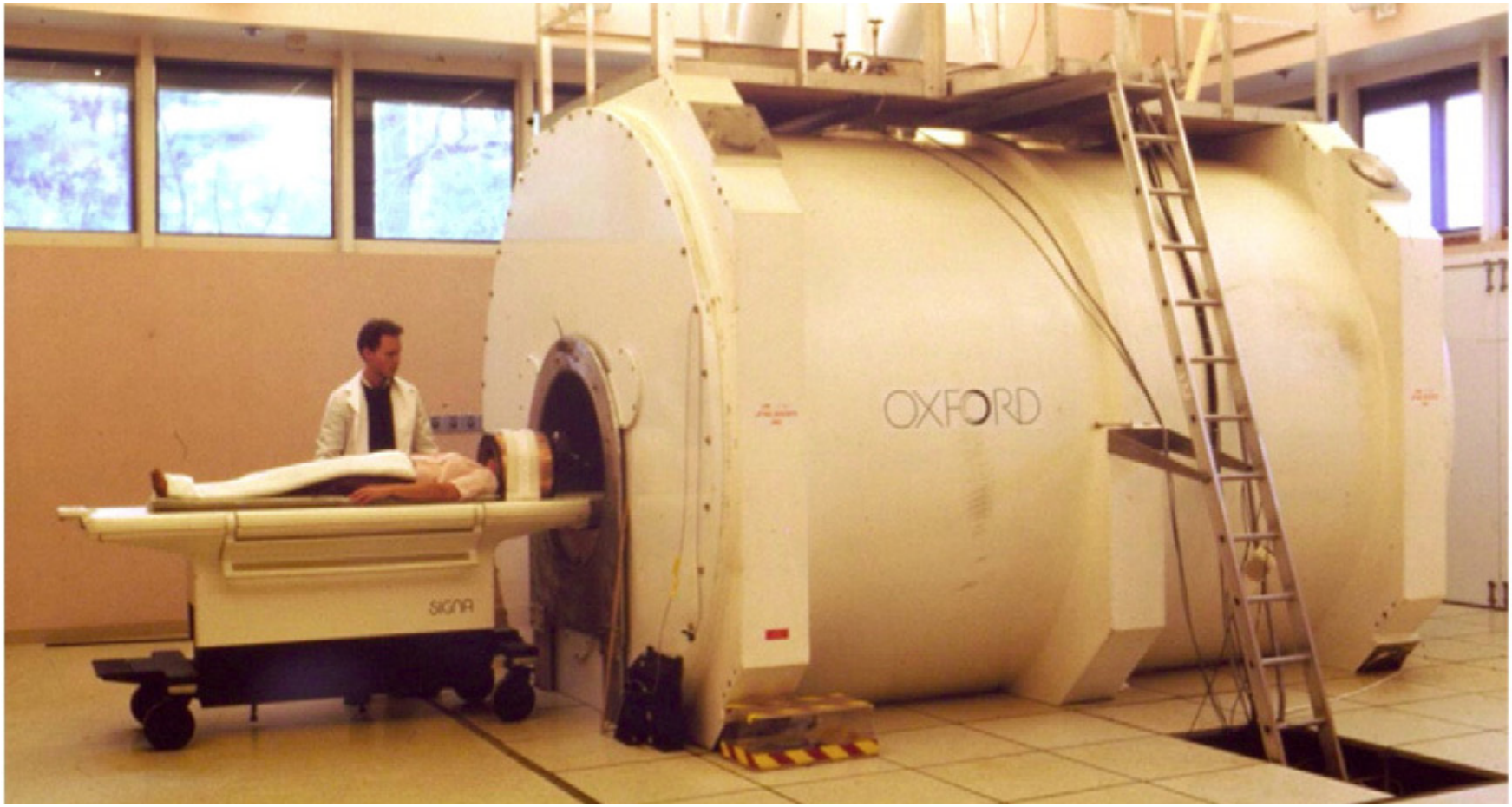


FIG. 2

NIH 4T

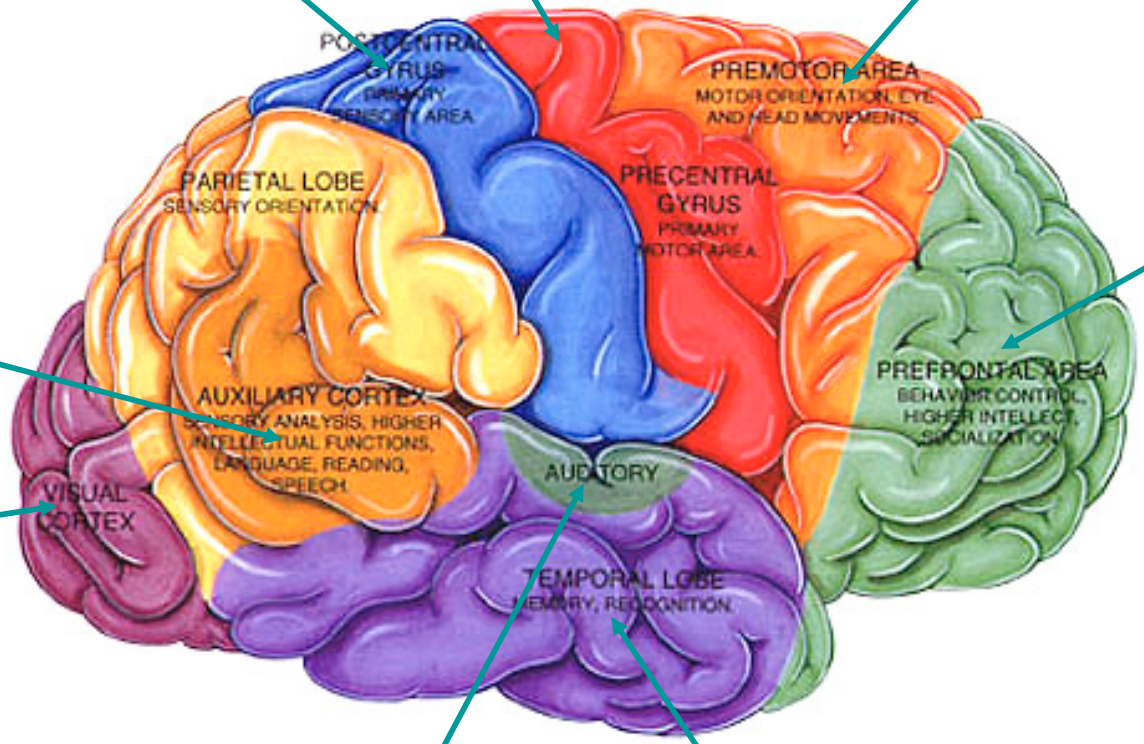


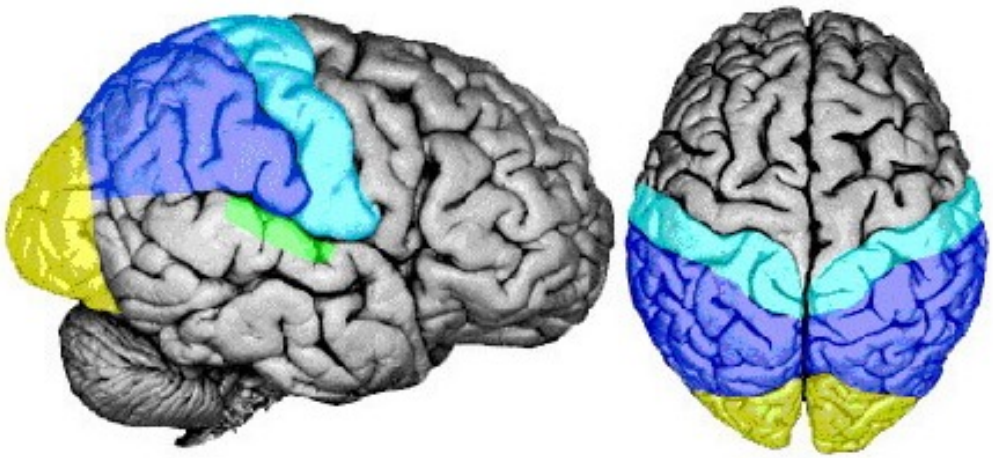
Siemens' new 7T

Five Key Factors For The Emergence of Functional MRI

1. Magnetic properties of red blood cells
2. Activation related hemodynamic changes
3. Spatial scale of brain activation
4. Echo Planar Imaging
5. Prevalence of MRI scanners

Brain Function



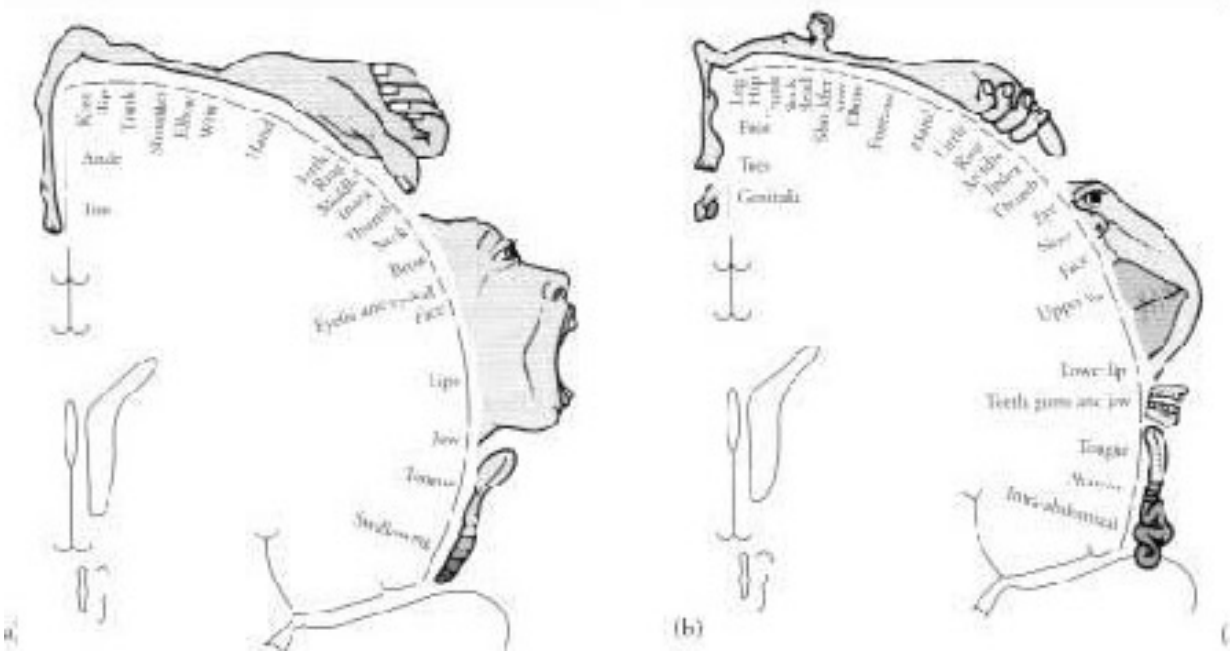


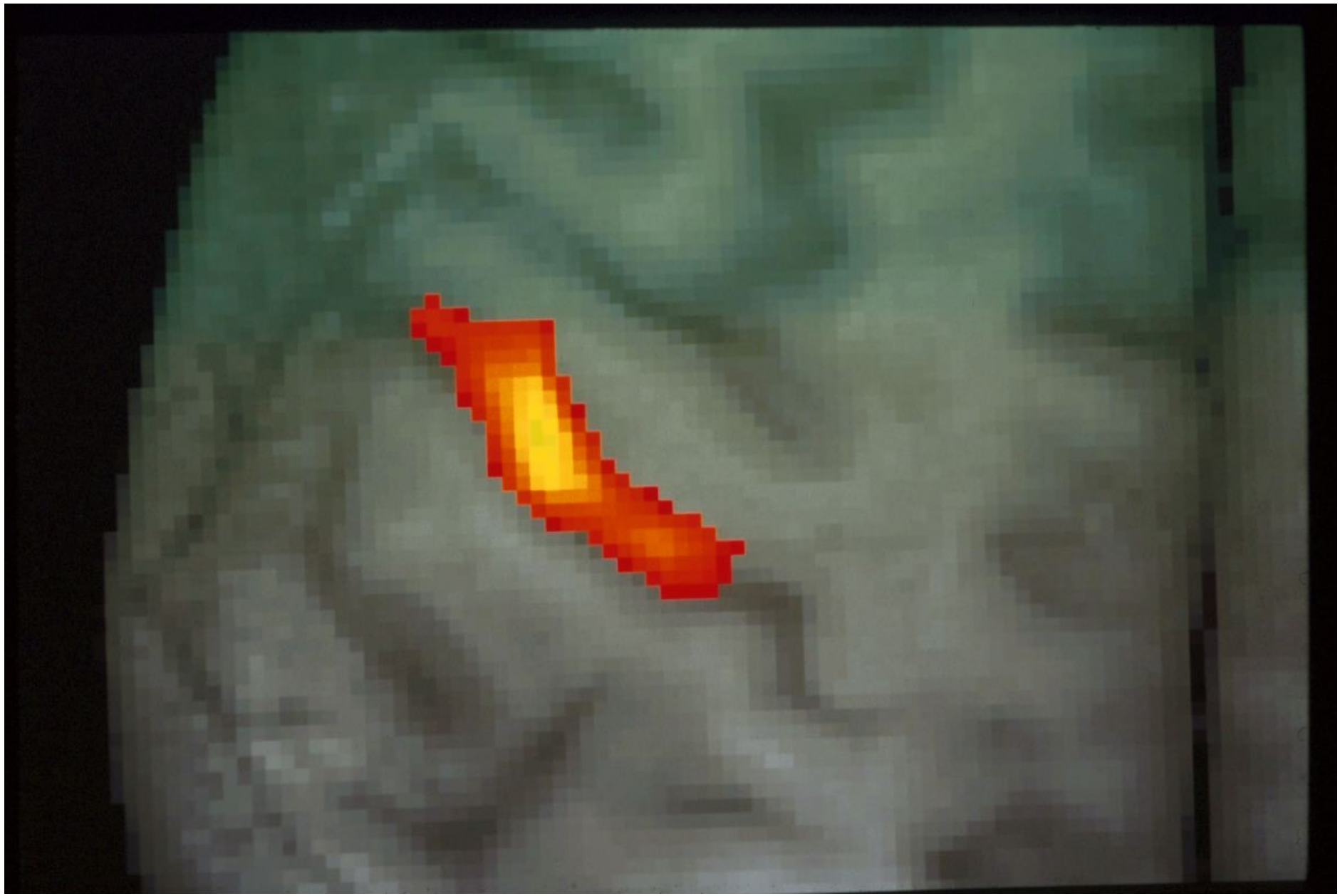
Parietal/
Somatosensory

Parietal/
Association Area

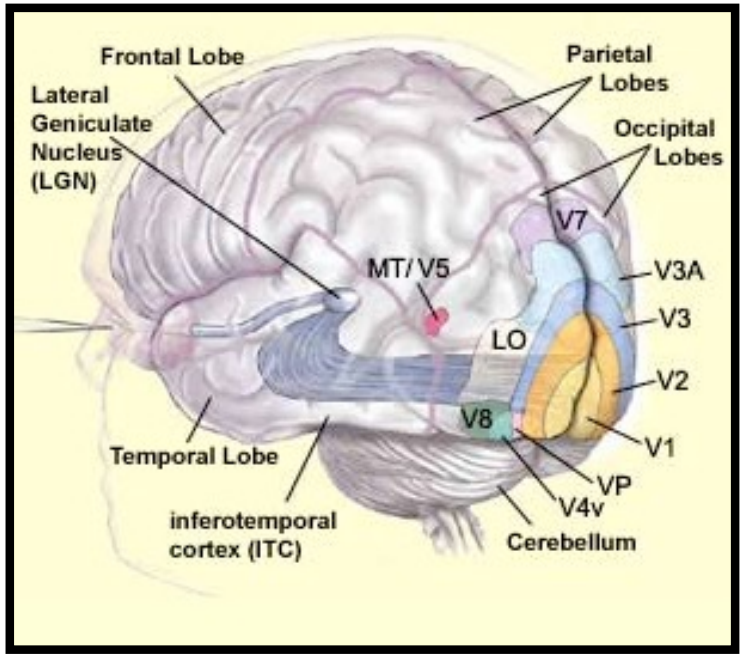
Occipital/Vision

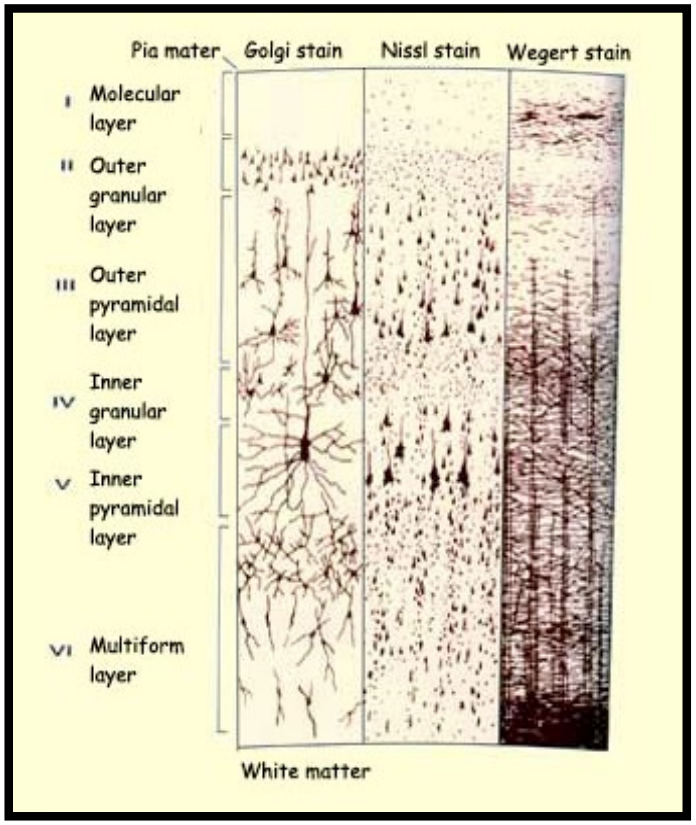
Auditory

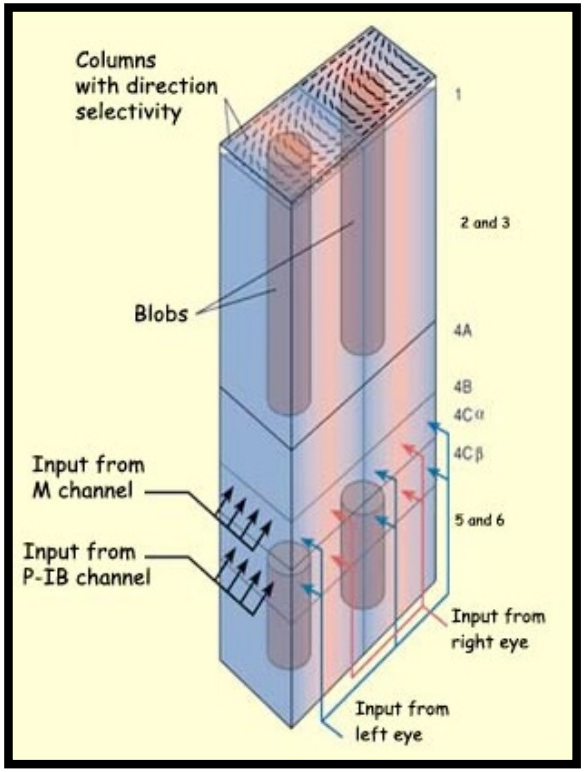




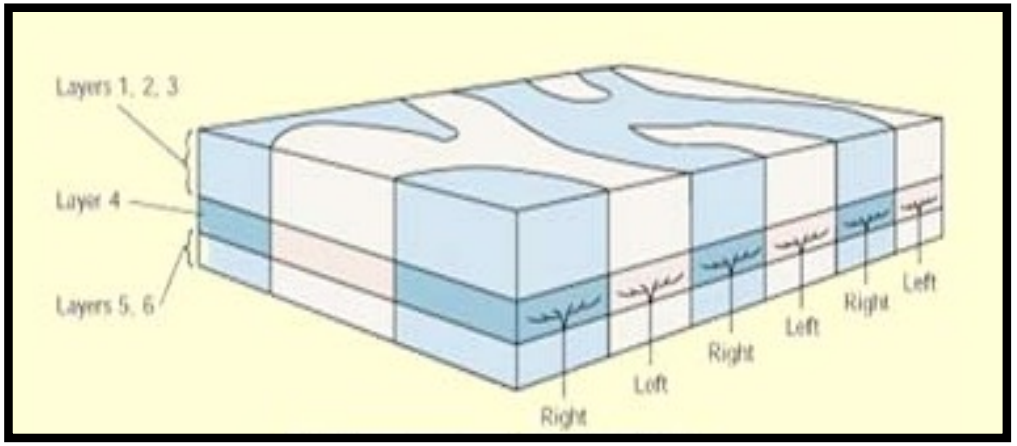
Visual Cortex Organization



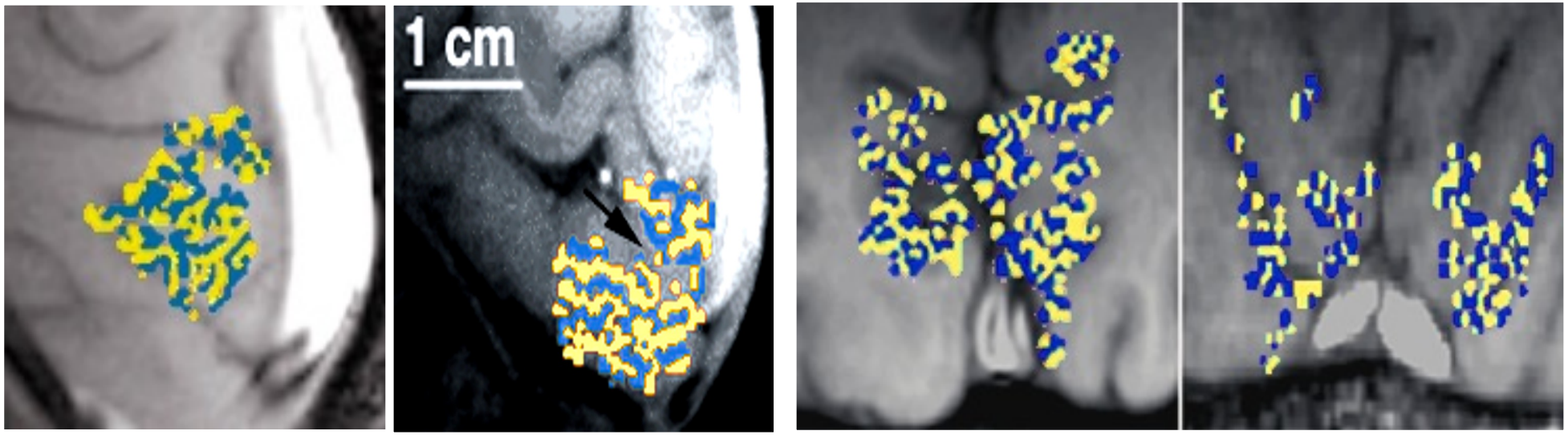




http://www.thebrain.mcgill.ca



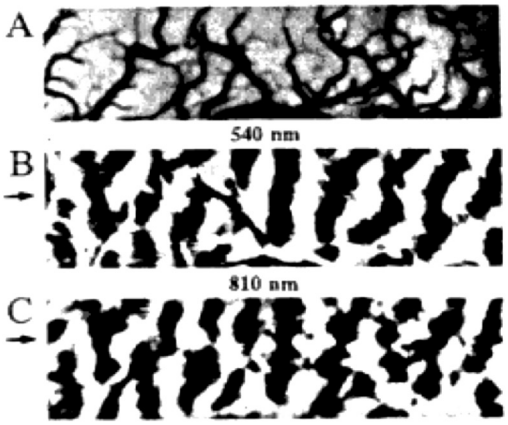
Ocular Dominance Column Mapping



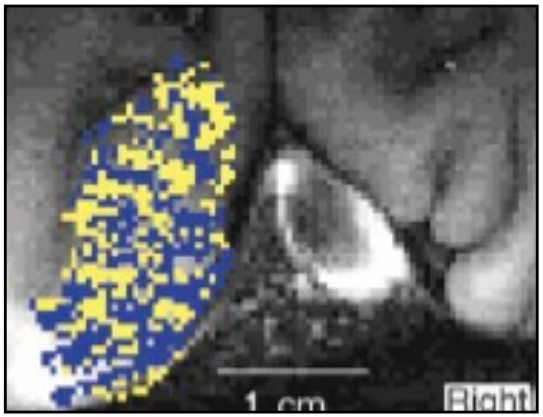
Menon, R. S., S. Ogawa, et al. (1997). J Neurophysiol 77(5): 2780-7.

0.54 x 0.54 in plane resolution

Optical Imaging

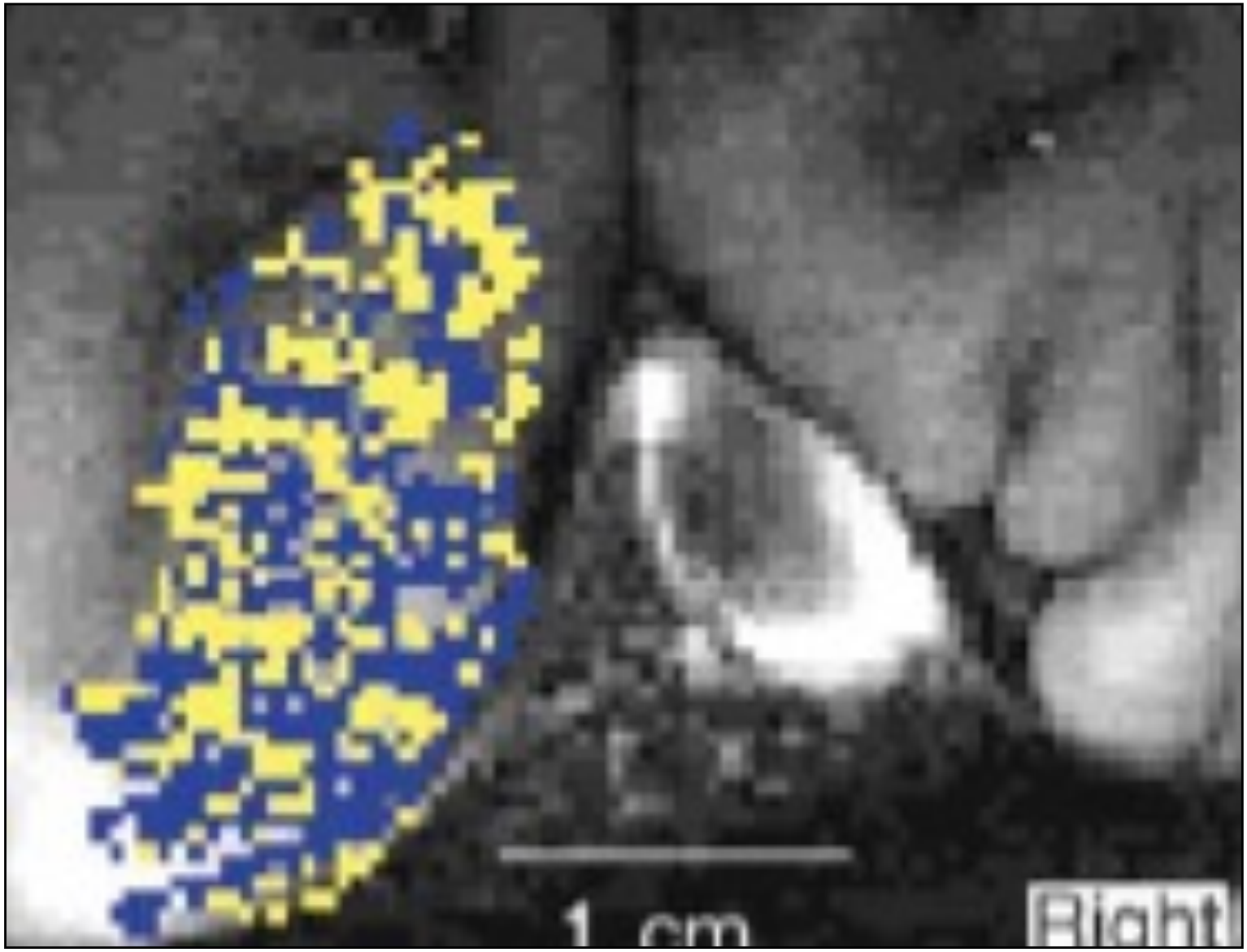


R. D. Frostig et. al, PNAS 87: 6082-6086, (1990).

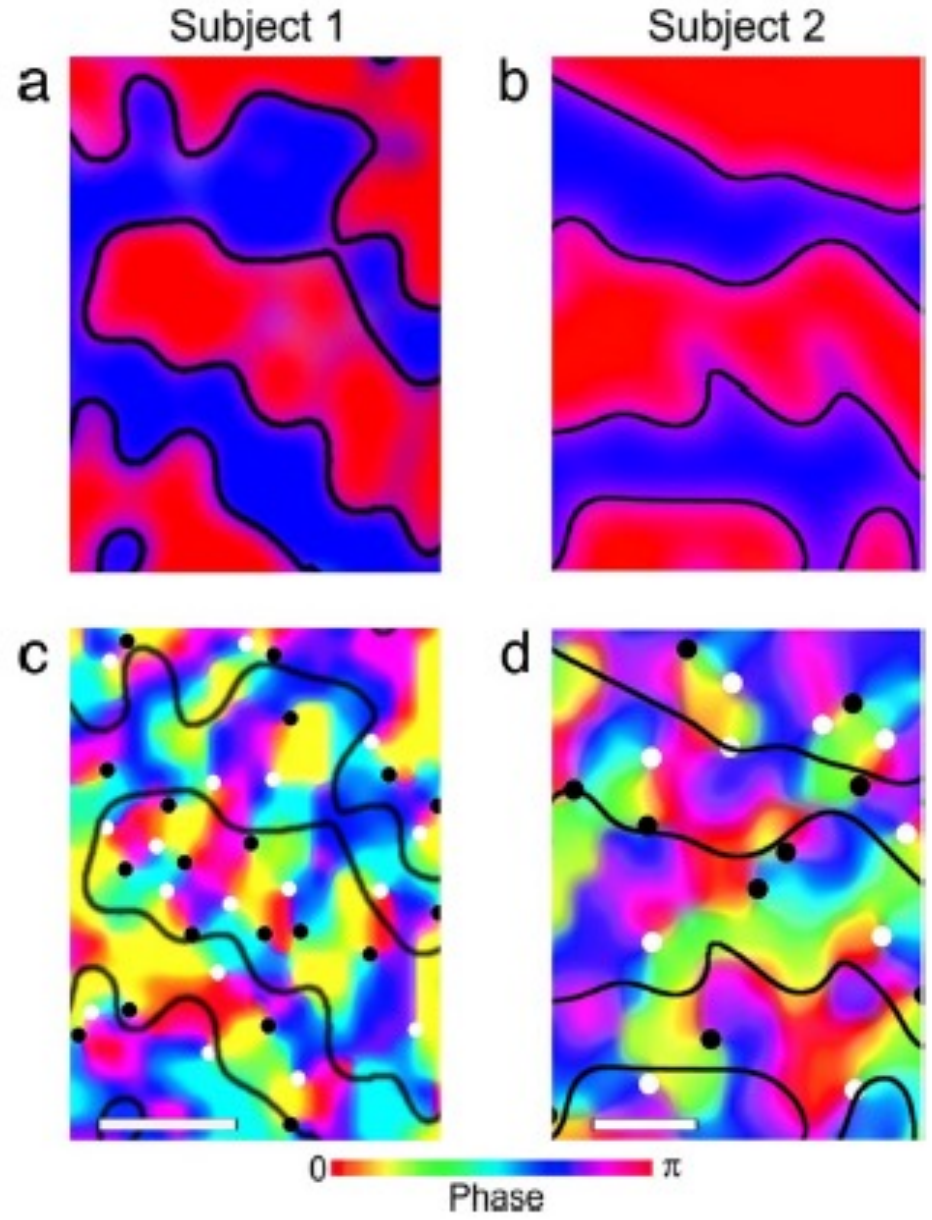


Cheng, et al. (2001) Neuron,32:359-374

0.47 x 0.47 in plane resolution

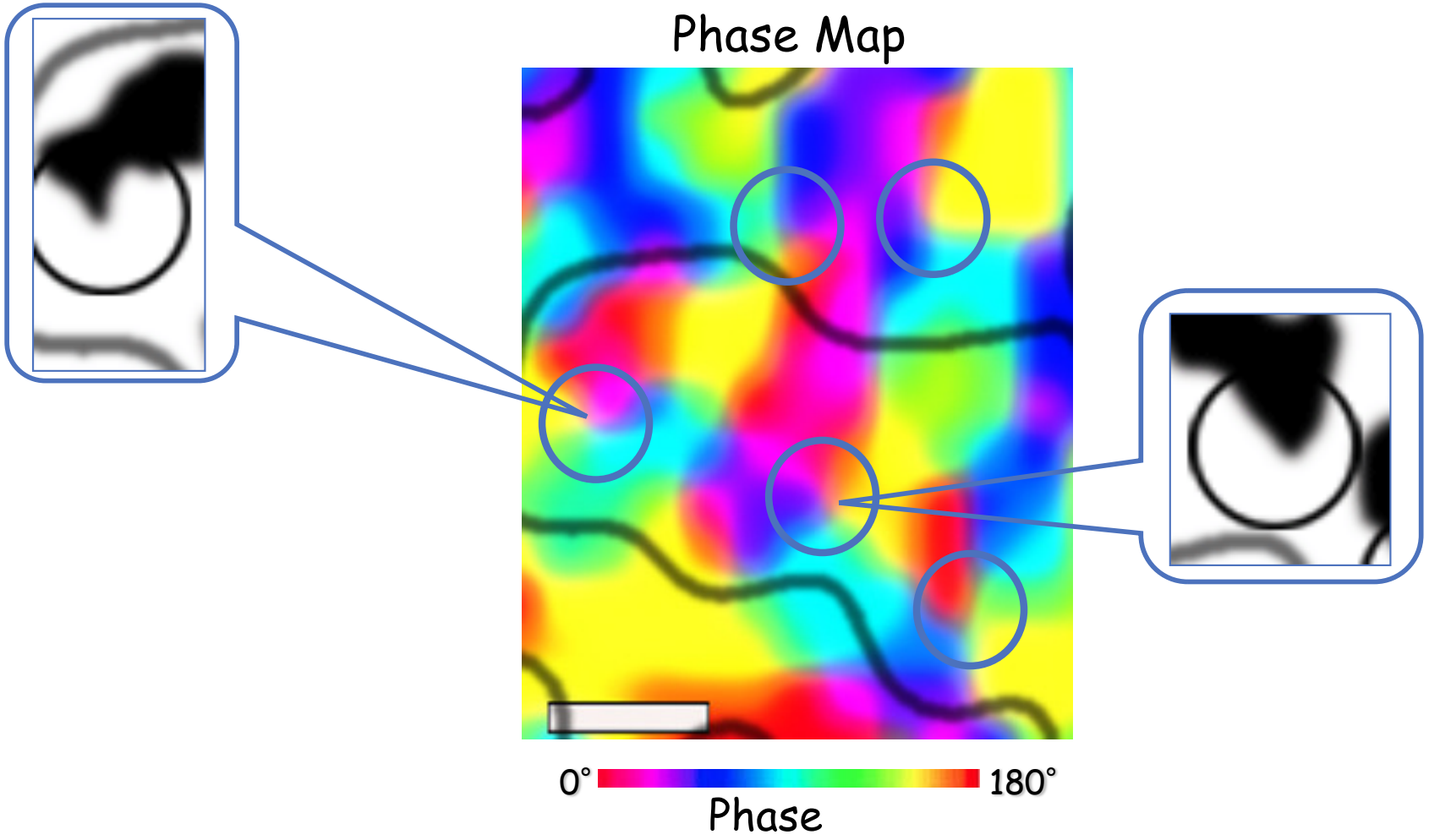


Cheng, et al. (2001) Neuron,32:359-374



Yacoub et al. PNAS 2008

Orientation Columns in Human V1 as Revealed by fMRI at 7T

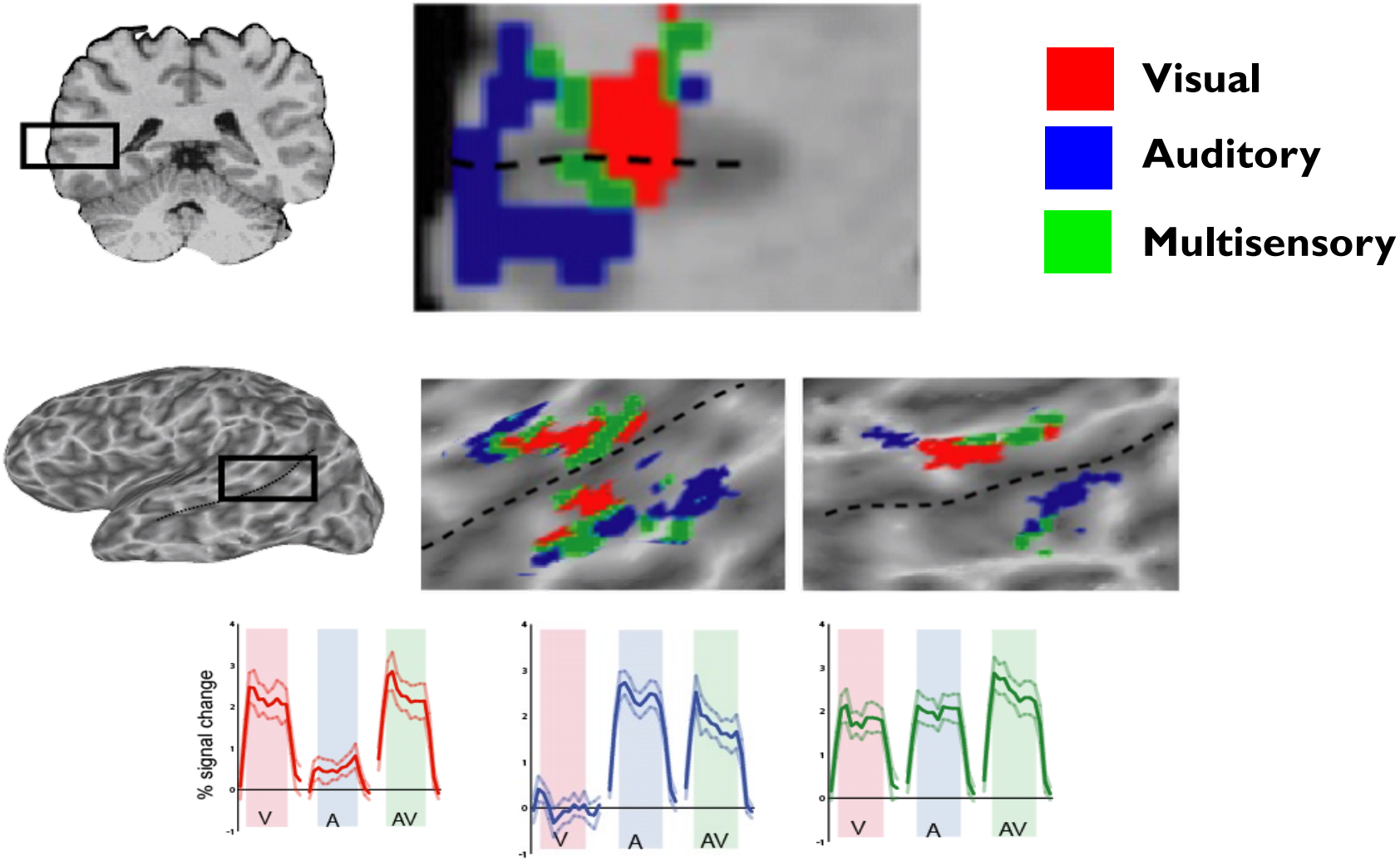


Scalebar = 0.5 mm

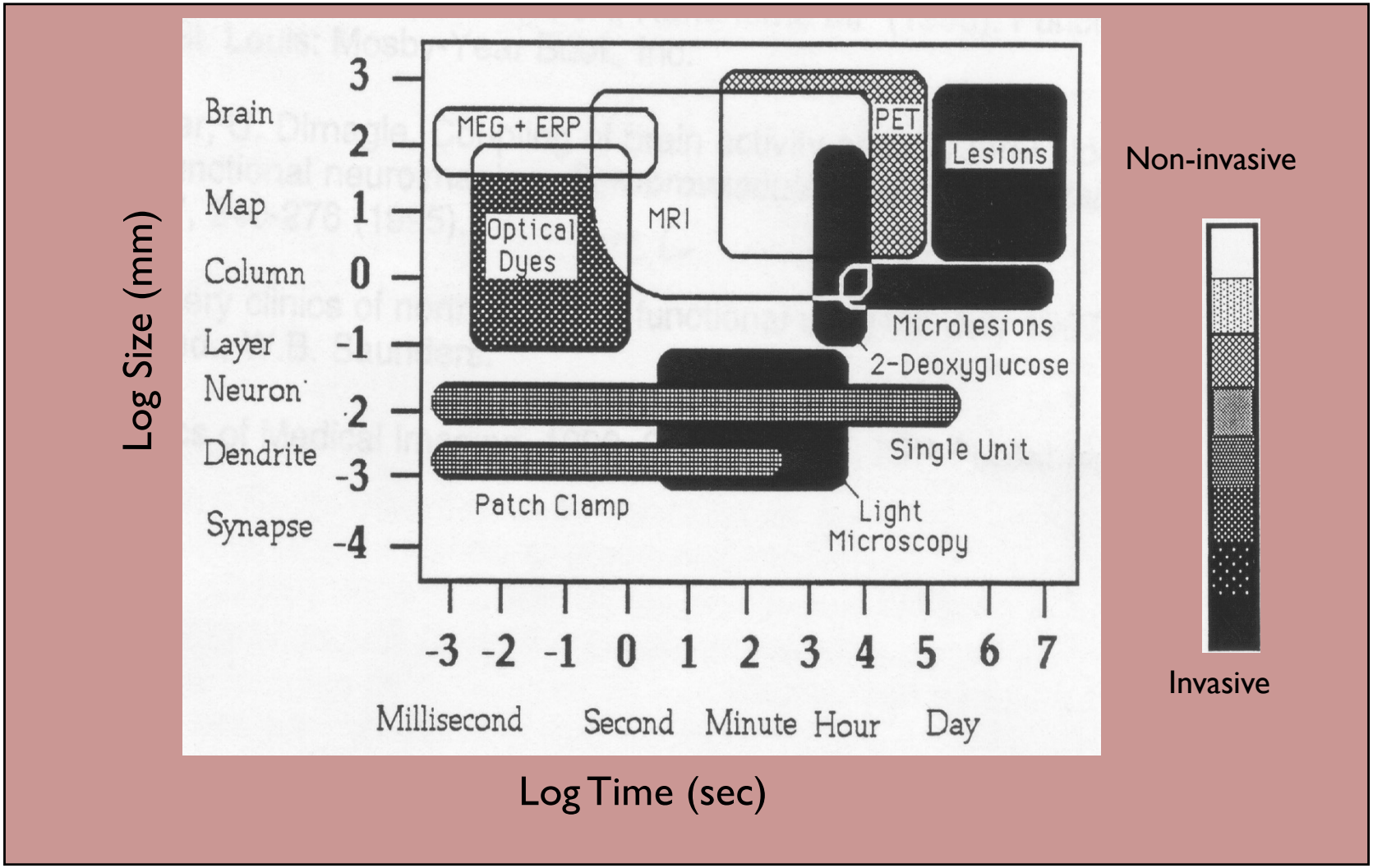
Yacoub et al. PNAS 2008

Multi-sensory integration

M.S. Beauchamp et al.,



Functional Neuroimaging Techniques

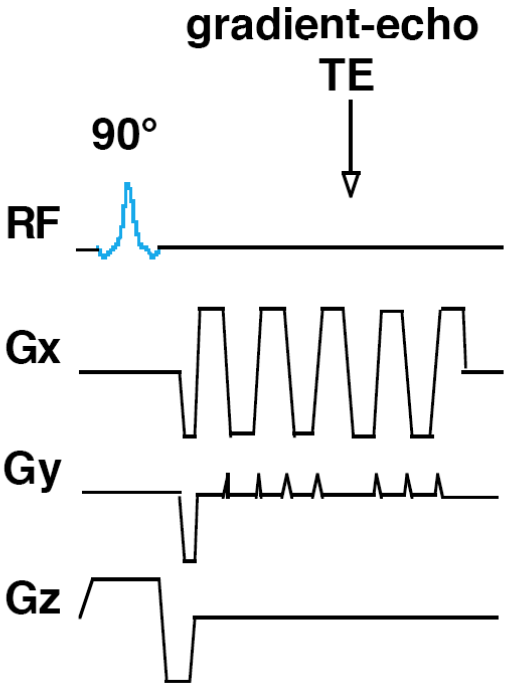


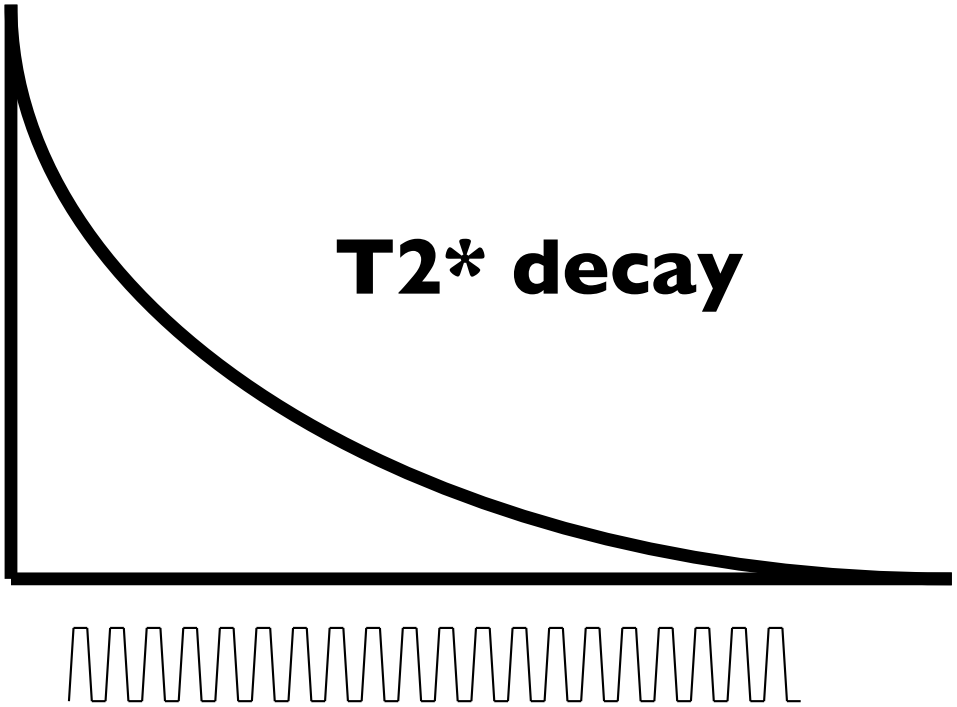
after Churchland and Sejnowski, 1988

Five Key Factors For The Emergence of Functional MRI

1. Magnetic properties of red blood cells
2. Activation related hemodynamic changes
3. Spatial scale of brain activation
4. Echo Planar Imaging
5. Prevalence of MRI scanners

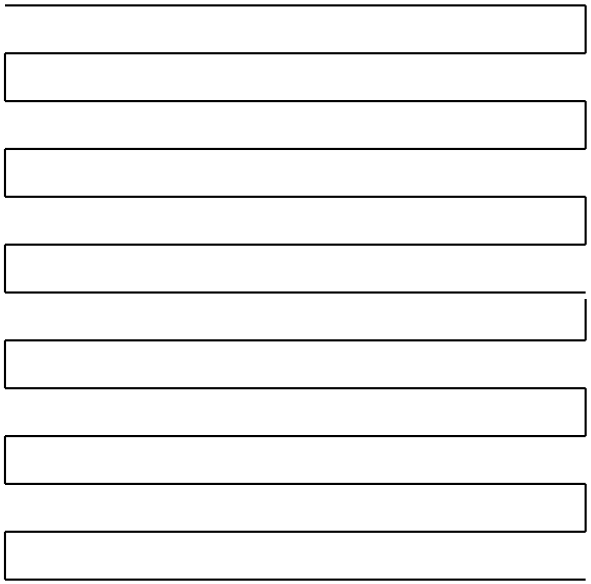
Single Shot Echo Planar Imaging (EPI)





EPI Readout Window

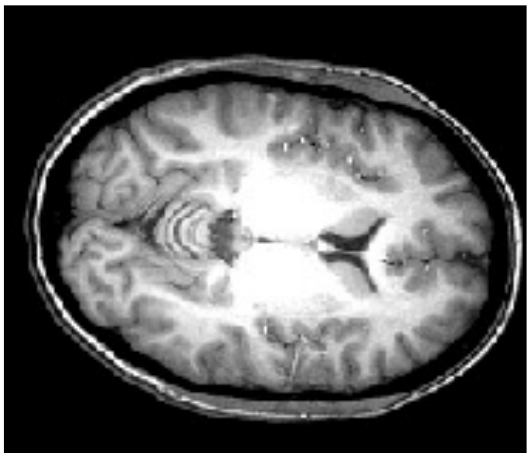
≈ 20 to 40 ms



MRI vs. fMRI

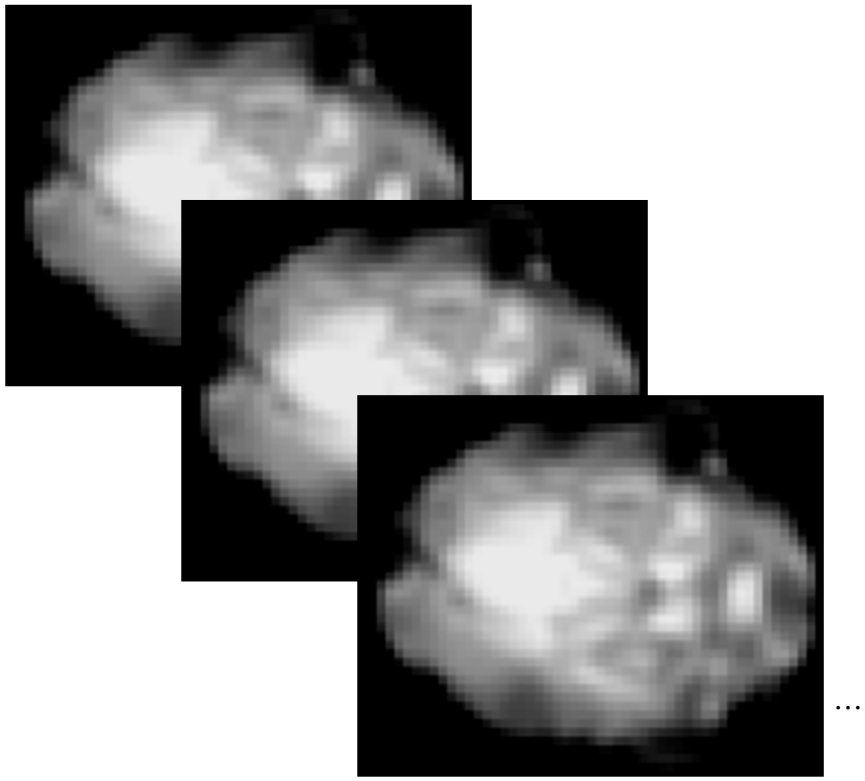
MRI

high resolution
(1 mm)



one image

fMRI

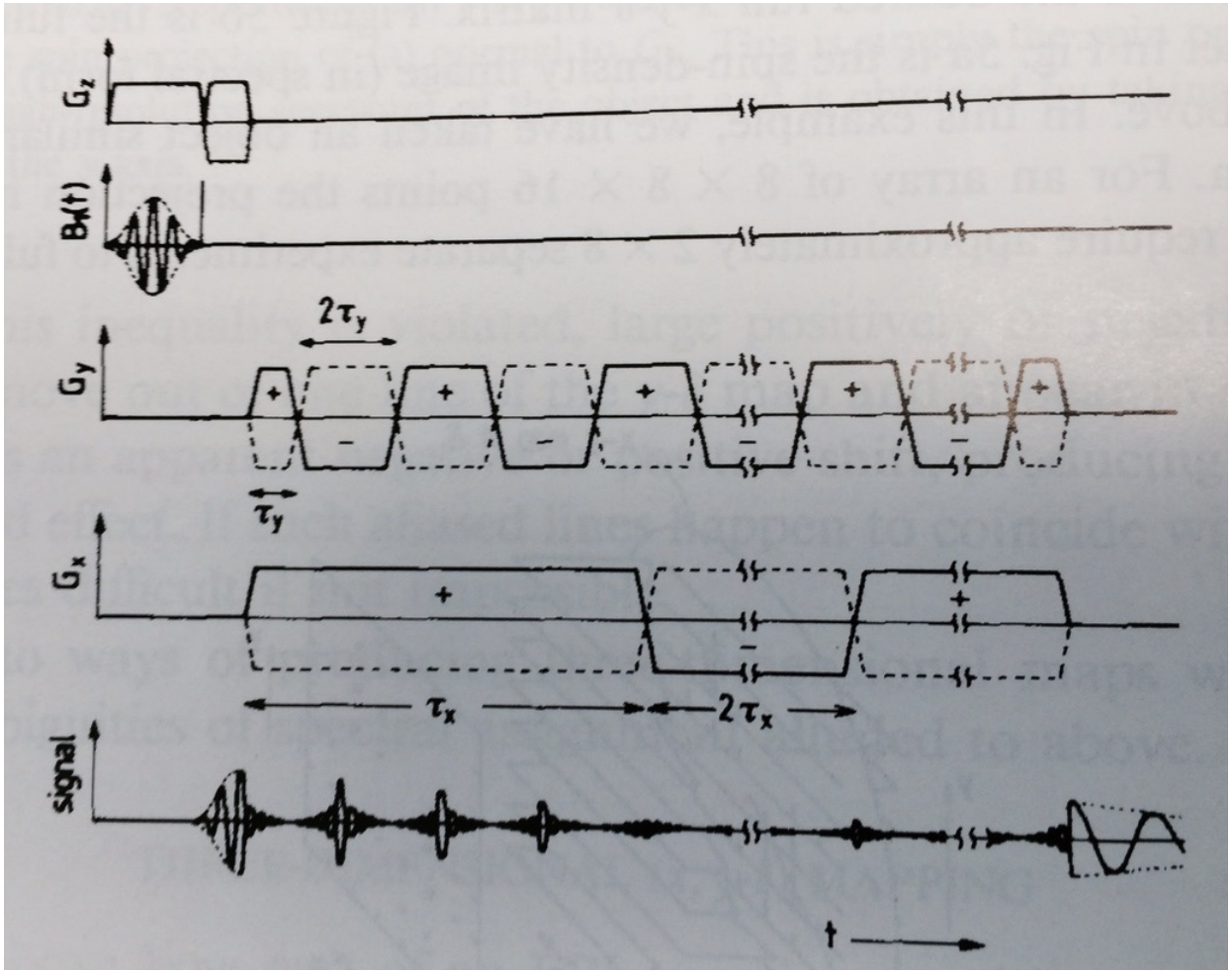


...

many images
(e.g., every 2 sec for 5 mins)

Sir Peter Mansfield conceived of Echo Planar Imaging long before it was physically possible...

Spatial Mapping of the Chemical Shift in NMR, P. Mansfield. Magnetic Resonance in Medicine 1, 370-386 (1984).



J. Phys. D: Appl. Phys. **19** (1986) L147–L151. Printed in Great Britain

LETTER TO THE EDITOR

A target field approach to optimal coil design

R Turner
Department of Physics, Nottingham University, Nottingham NG7 2RD, UK

Received 2 May 1986

Abstract. Using a Fourier–Bessel expansion of the magnetic field generated by currents flowing on a cylinder, the relationship between current and field may be inverted. Hence the current density required to generate a specified target field B_z on the surface of a cylinder of smaller radius may be evaluated. Gradient, solenoidal and shim coil designs based on this approach provide exceptionally large usable volumes while remaining compact and, if necessary, of low inductance.

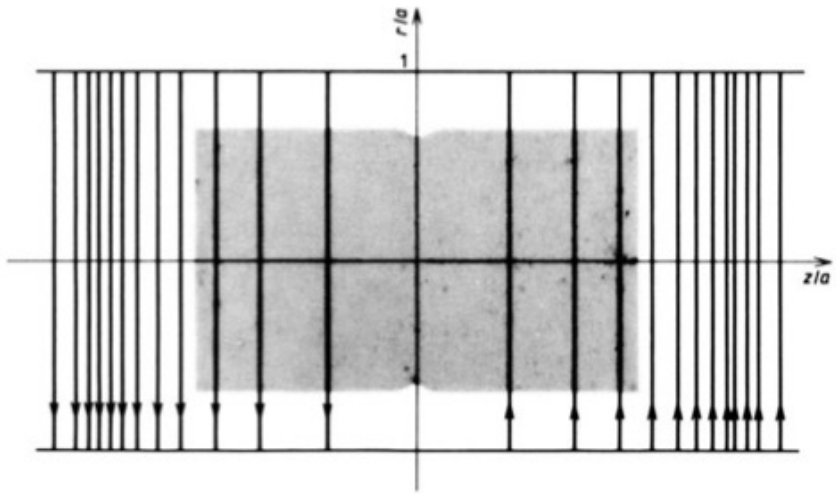


Figure 2. The arc configuration for a longitudinal gradient coil. The volume within which the gradient is uniform to 5% is shaded. Wire positions:

MAGNETIC RESONANCE IN MEDICINE 8, 110–115 (1988)

Snapshot Head Imaging at 0.5 T Using the Echo Planar Technique

R. J. ORDIDGE, R. COXON, A. HOWSEMAN, B. CHAPMAN, R. TURNER, M. STEHLING, AND P. MANSFIELD

Department of Physics, University of Nottingham, Nottingham NG7 2RD, United Kingdom

Received April 22, 1988; revised June 17, 1988

The echo planar imaging (EPI) method and related variants of this technique can produce complete two-dimensional images from the data collected in a single experiment lasting a fraction of a second. EPI methods are used at 0.5 T to produce snapshot images of the human head with a spatial resolution of less than 2 mm.

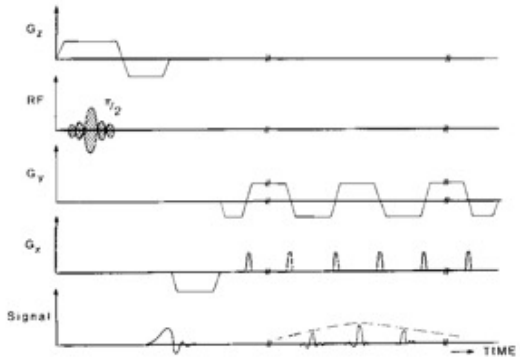
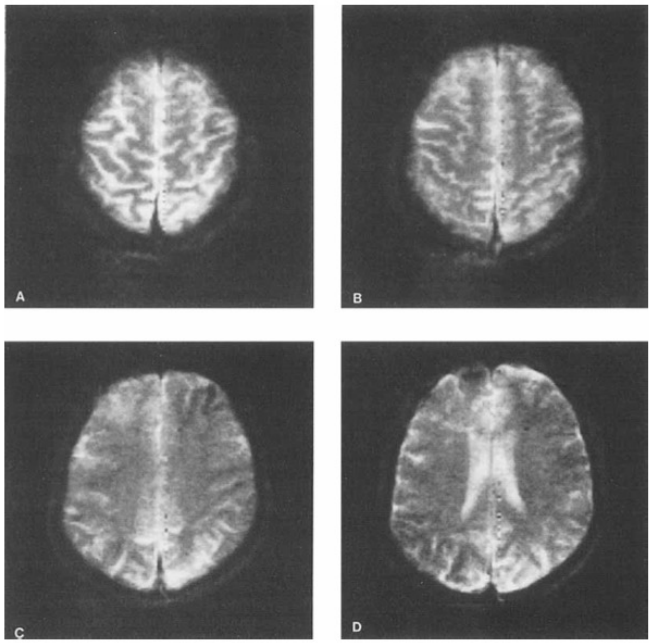
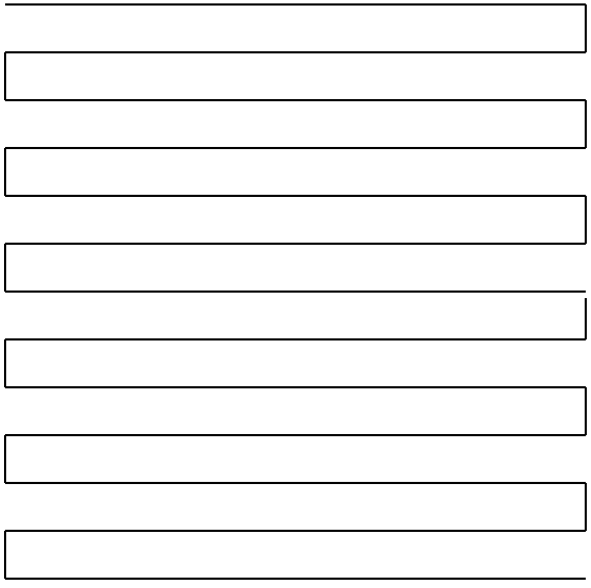


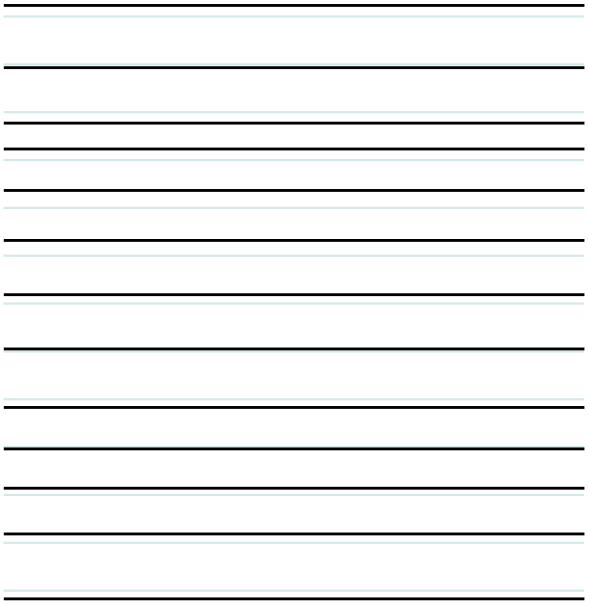
FIG. 2. The gradient and RF pulse sequence used in the MBEST experiment. An unphased image is produced by taking the magnitude of the Fourier transformed data. The largest spin echoes occur midway through the experiment, thus providing discrimination against signal with a short T_2 relaxation time.

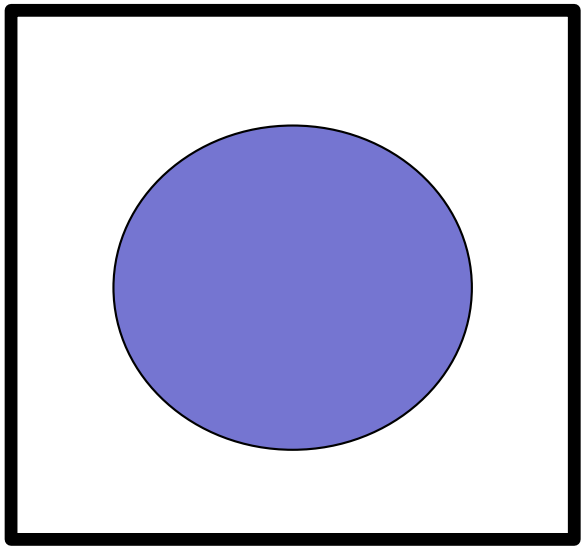


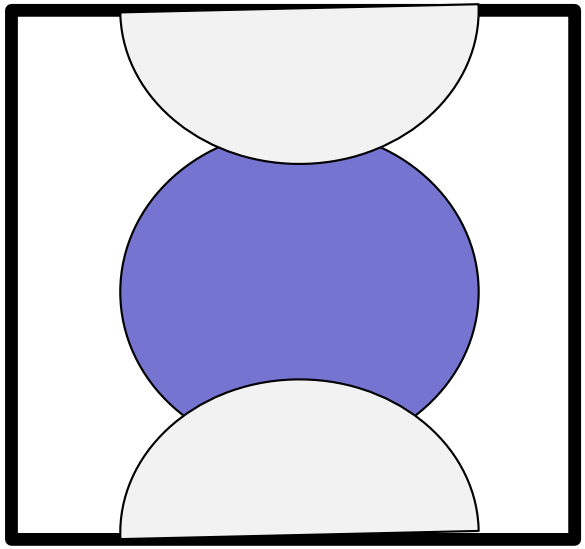
30 ms



10 sec
to
1 min





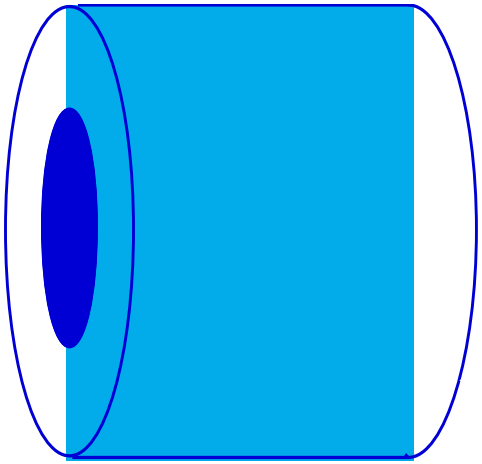


Approximate EPI Timeline

1976-84 P. Mansfield conceives of EPI
1989 EPI of humans emerges on a handful of scanners
3 x 3 x 3-10 mm^3
1989 ANMR retrofitted with GE scanners for EPI
1991 Home built head gradient coils perform EPI
1996 EPI is standard on clinical scanners
2000 Gradient performance continues to increase
2002 Parallel imaging allows for higher resolution EPI
2006 1.5 x 1.5 x 1.5 mm^3 single shot EPI possible
2009 At 7T sub – mm single shot EPI for fMRI is possible

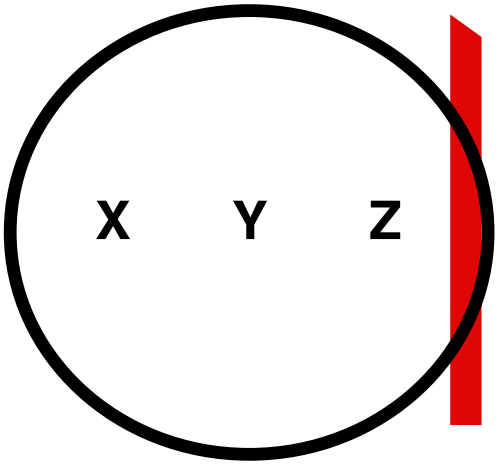
Imaging System Components

Magnet

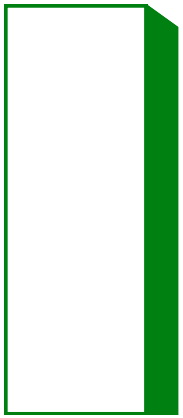


RF Receiver

Viewing Console

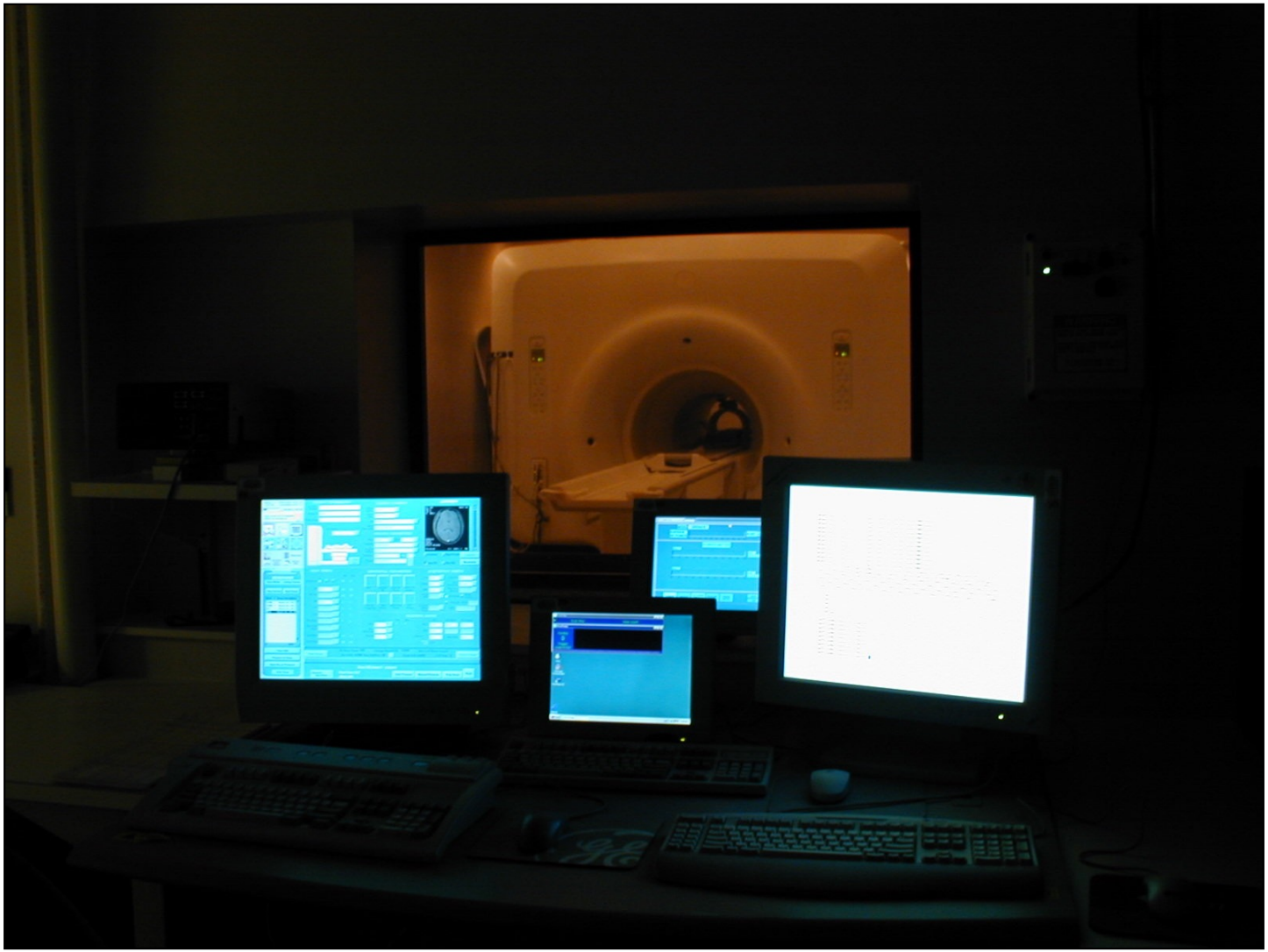


Gradient Power Systems



RF Transmitter

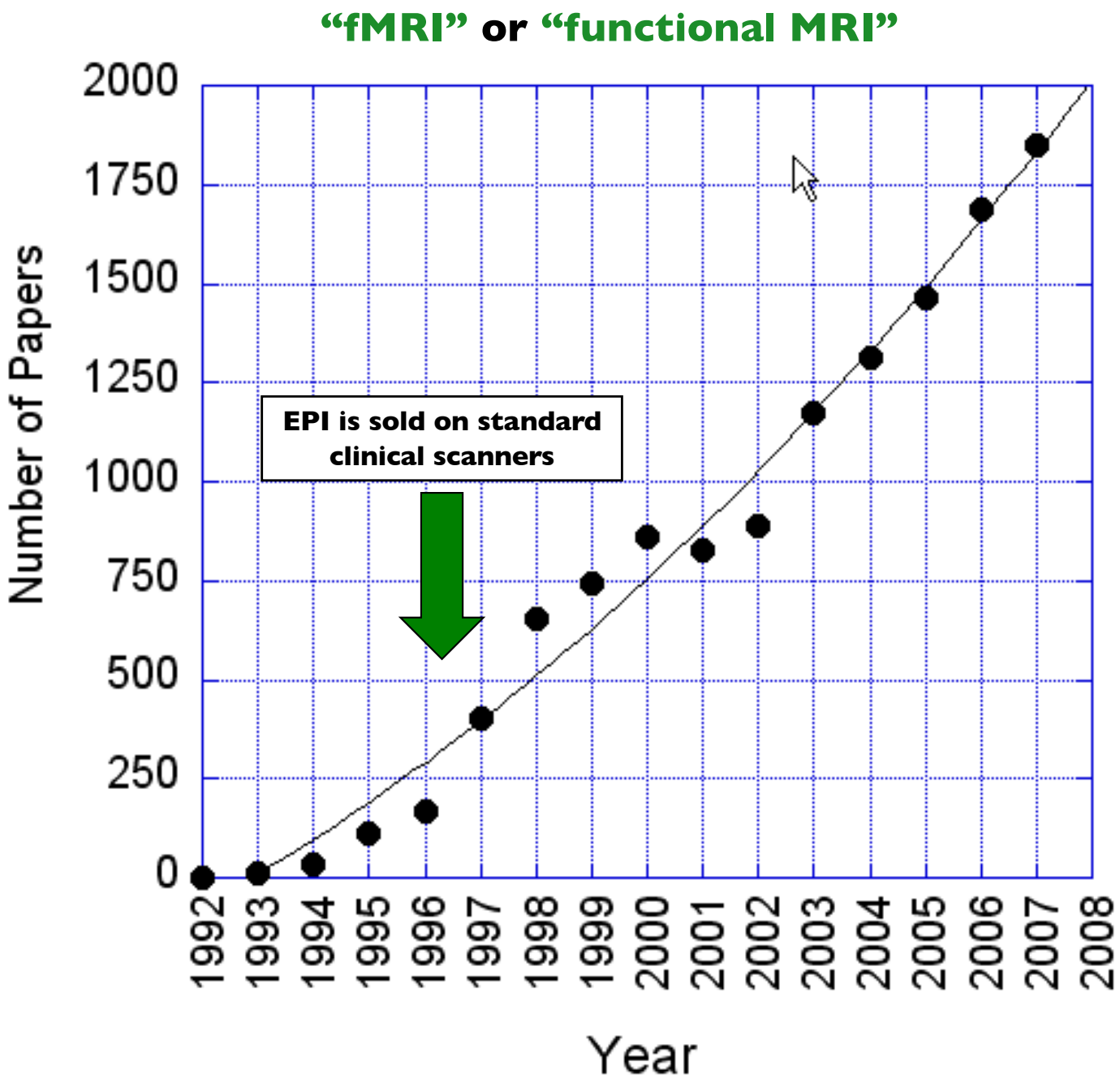
Scan Controller



Five Key Factors For The Emergence of Functional MRI

1. Magnetic properties of red blood cells
2. Activation related hemodynamic changes
3. Spatial scale of brain activation
4. Echo Planar Imaging
5. Prevalence of MRI scanners

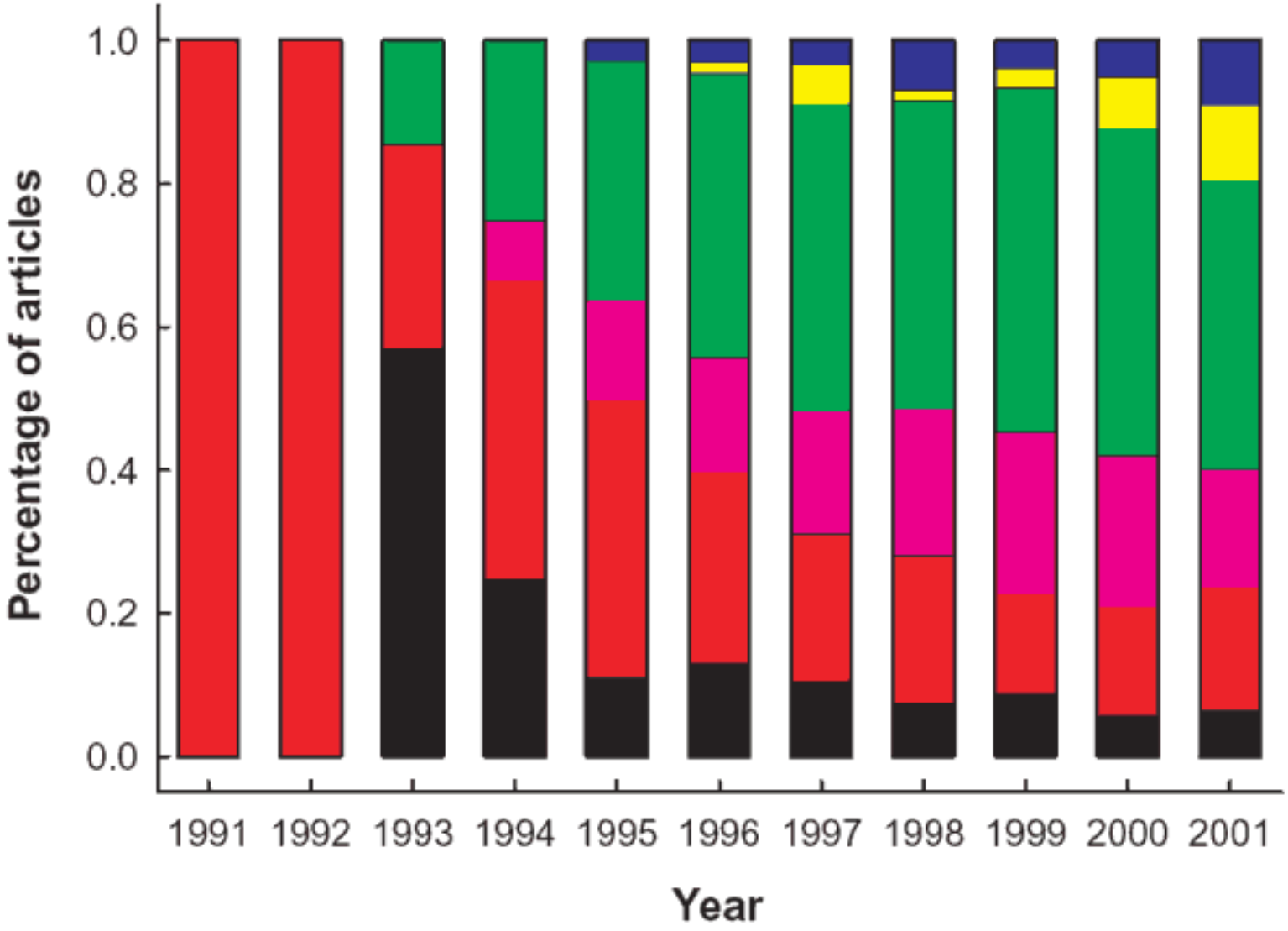
Scopus: Articles or Reviews Published per Year



How it all came together…

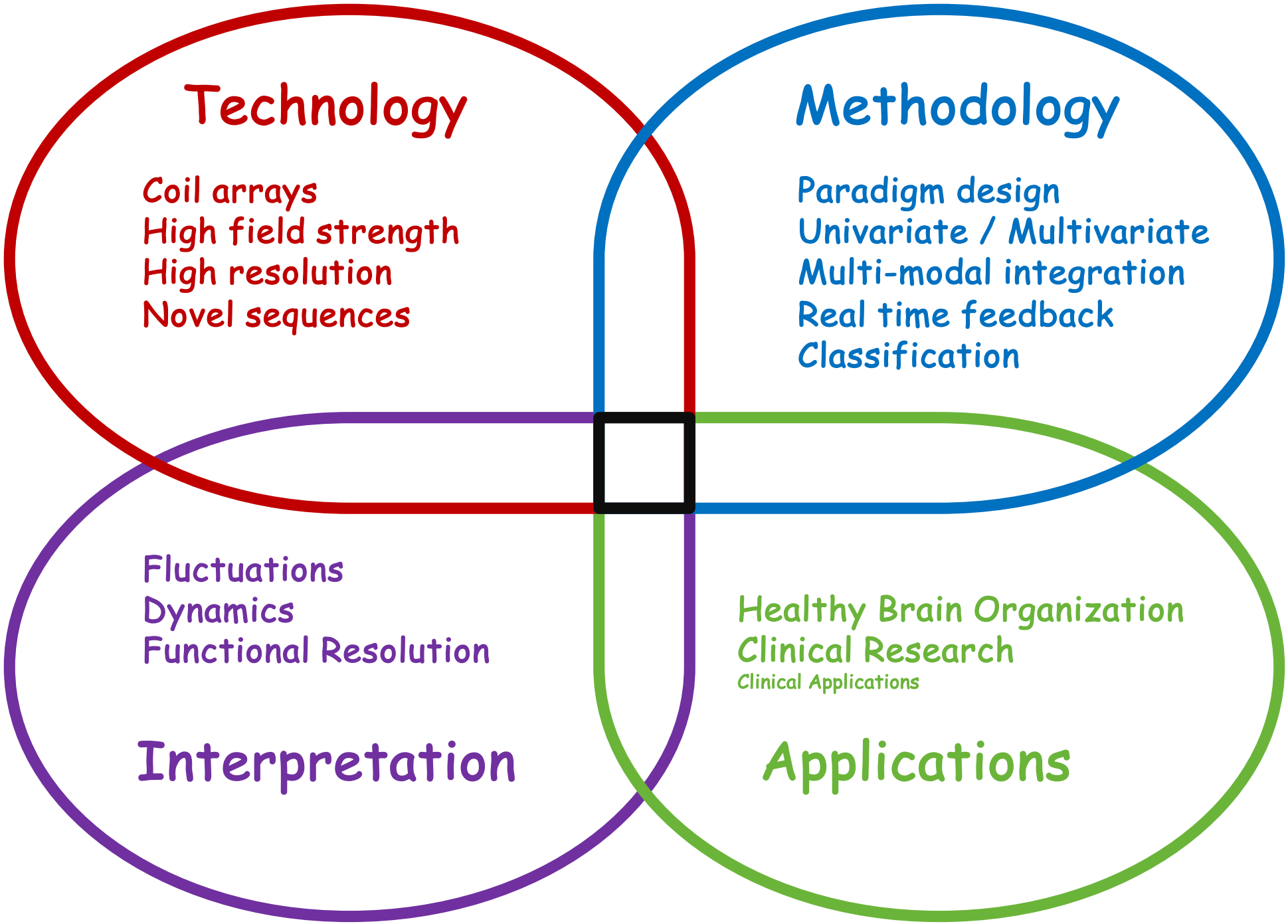
Five Key Factors For The Emergence of Functional MRI

1. **Magnetic properties of red blood cells**
2. **Activation related hemodynamic changes**
3. **Spatial scale of brain activation**
4. **Echo Planar Imaging**
5. **Prevalence of MRI scanners**



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

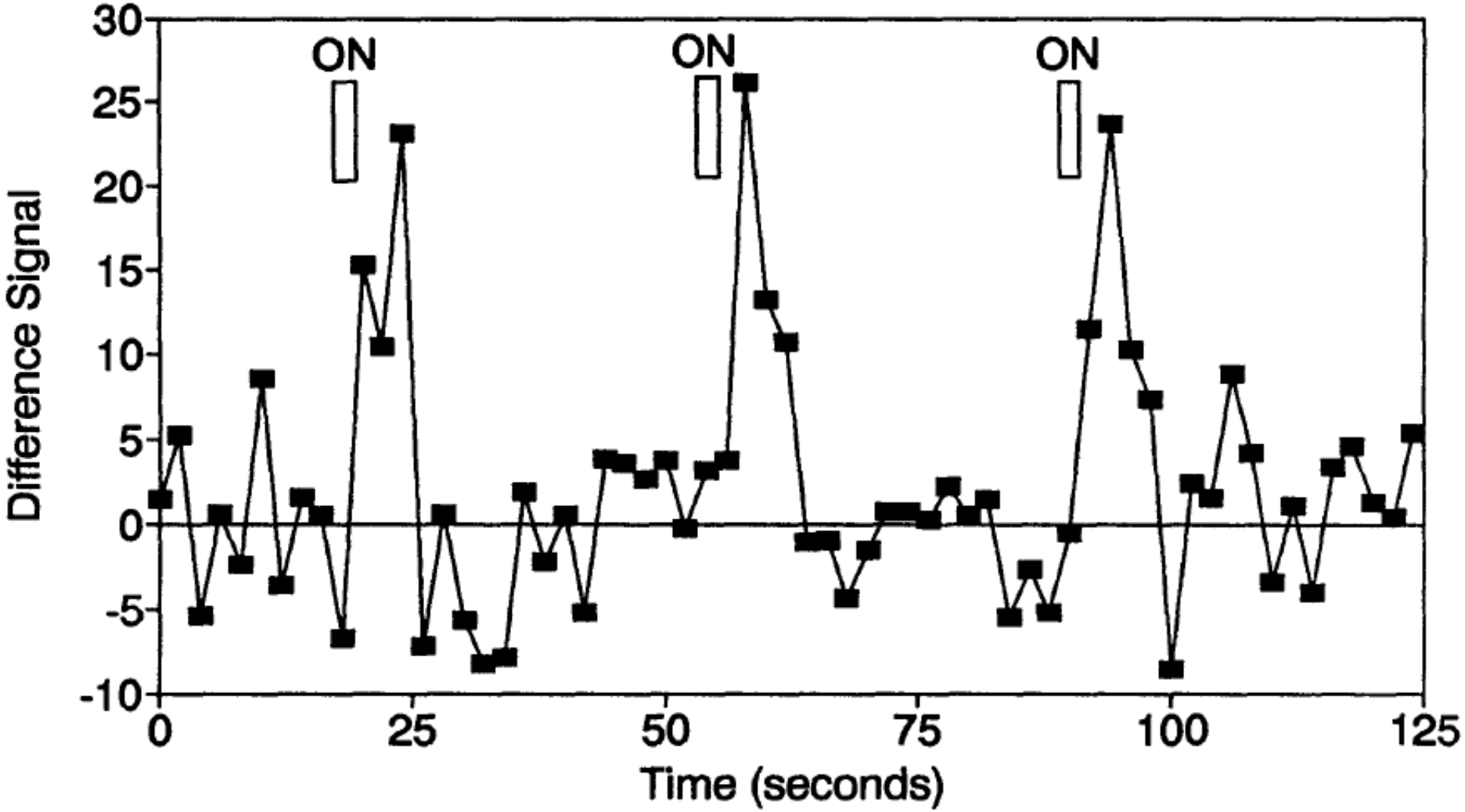
J. Illes, M. P. Kirschen, J. D. E. Gabrielli,
Nature Neuroscience, 6 (3)m p.205


Technology
Coil arrays
High field strength
High resolution
Novel sequences
Methodology
Paradigm design
Univariate / Multivariate
Multi-modal integration
Real time feedback
Classification
Fluctuations
Dynamics
Functional Resolution
Interpretation
Healthy Brain Organization
Clinical Research
Clinical Applications
Applications

A bit more history…

- Event-Related fMRI (1993, 1996)
- Retinotopy (1995)
- Resting State fMRI (1995…2006)
- Ocular Dominance Columns (1997)
- High Field and Multi-channel Receive (2000)
- fMRI “Decoding” (2001)
- Intracortical recordings and fMRI (2001)
- DARPA Brain Reading Competition (2006)
- Approval for Pre-surgical Mapping (2007)

The first event-related studies.



Blamire, A. M., et al. (1992). "Dynamic mapping of the human visual cortex by high-speed magnetic resonance imaging." Proc. Natl. Acad. Sci. USA 89: 11069-11073.

Proc. Natl. Acad. Sci. USA
Vol. 93, pp. 14878–14883, December 1996
Neurobiology

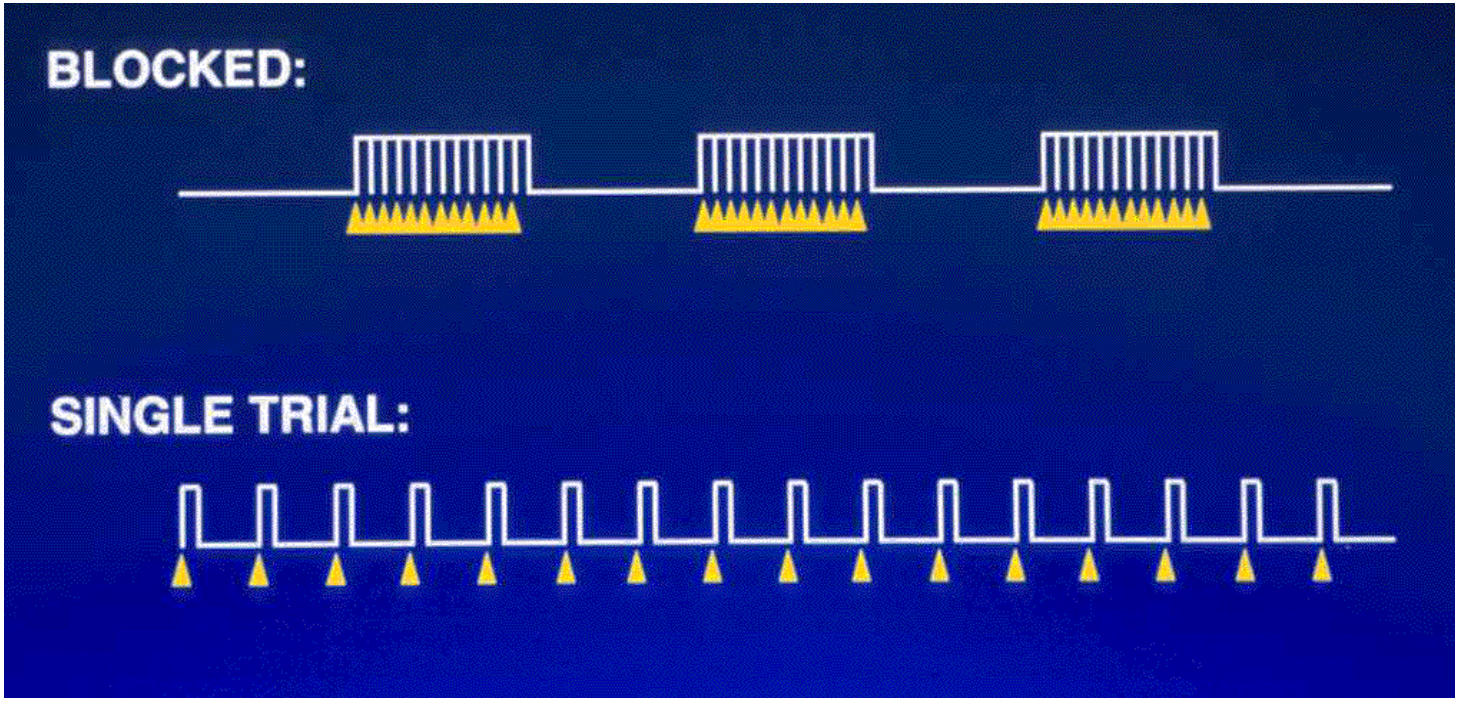
Detection of cortical activation during averaged single trials of a cognitive task using functional magnetic resonance imaging

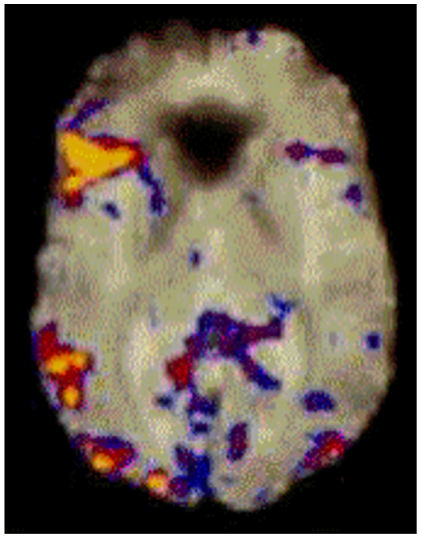
(neuroimaging/single trial/language/prefrontal)

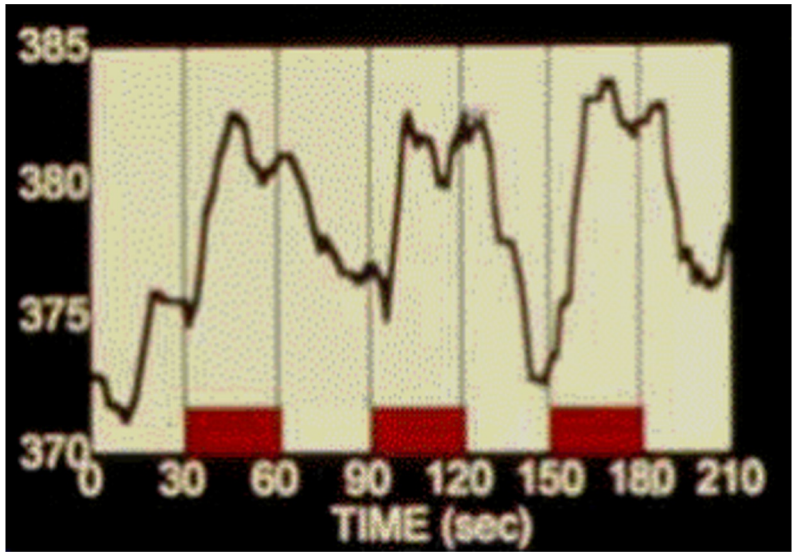
RANDY L. BUCKNER[†‡§¶], PETER A. BANDETTINI[†‡], KATHLEEN M. O'CRAVEN[†‖], ROBERT L. SAVOY[†‖], STEVEN E. PETERSEN[**††], MARCUS E. RAICHLE[§**††], AND BRUCE R. ROSEN[†‡]

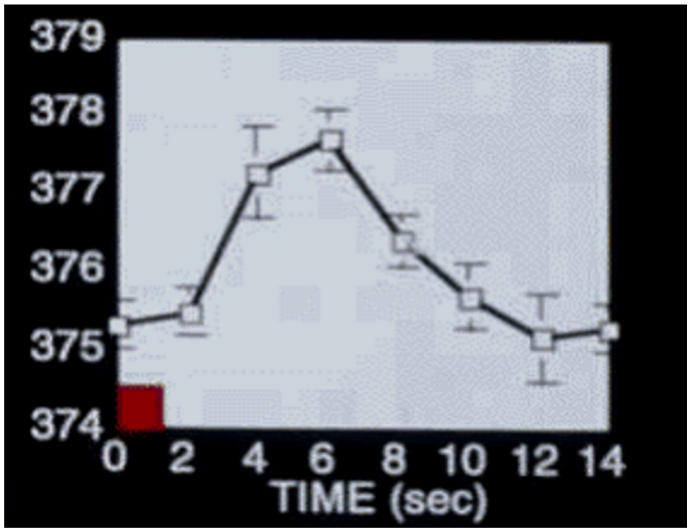
[†]Department of Radiology, Massachusetts General Hospital Nuclear Magnetic Resonance Center, Charlestown, MA 02129; [‡]Harvard University Medical School, Boston, MA 02115; [‖]Rowland Institute, Cambridge, MA 02142; and [**]Departments of Neurology and Neurosurgery and McDonnell Center for the Study of Higher Brain Function, and Departments of [§]Radiology and [††]Anatomy and Neurobiology, Washington University Medical School, St. Louis, MO 63110

Contributed by Marcus E. Raichle, September 4, 1996


BLOCKED:
SINGLE TRIAL:



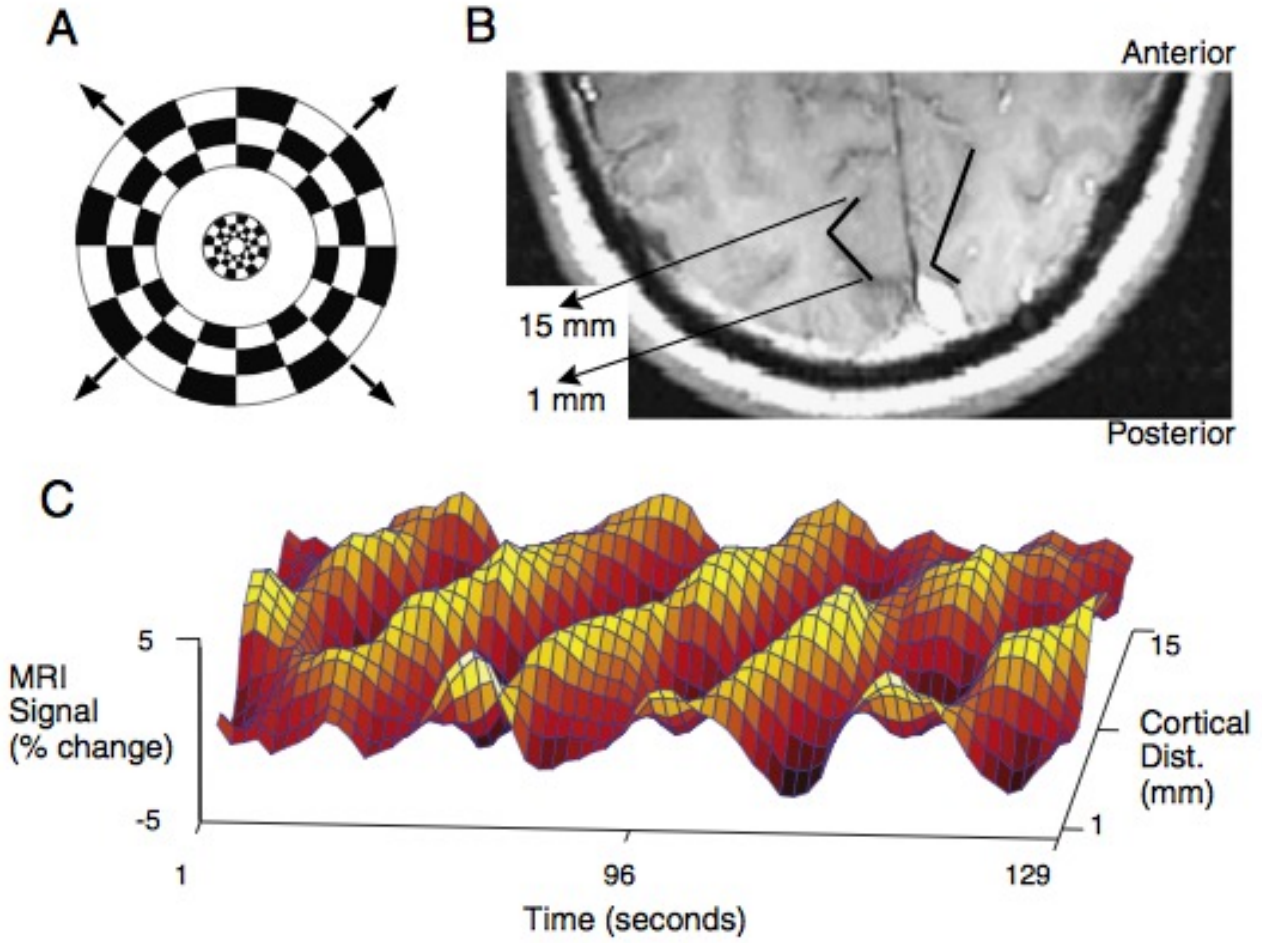

385
380
375
370
0 30 60 90 120 150 180 210
TIME (sec)


379
378
377
376
375
374
0 2 4 6 8 10 12 14
TIME (sec)

fMRI of human visual cortex

Stephen A. Engel
David E. Rumelhart
Brian A. Wandell
Department of Psychology,
Adrian T. Lee
Gary H. Glover
Department of Radiology,
Eduardo-Jose Chichilnisky
Neuroscience Program,
Michael N. Shadlen
Department of Neurobiology,
Stanford University, Stanford,
California 94305, USA

NATURE · VOL 369 · 16 JUNE 1994



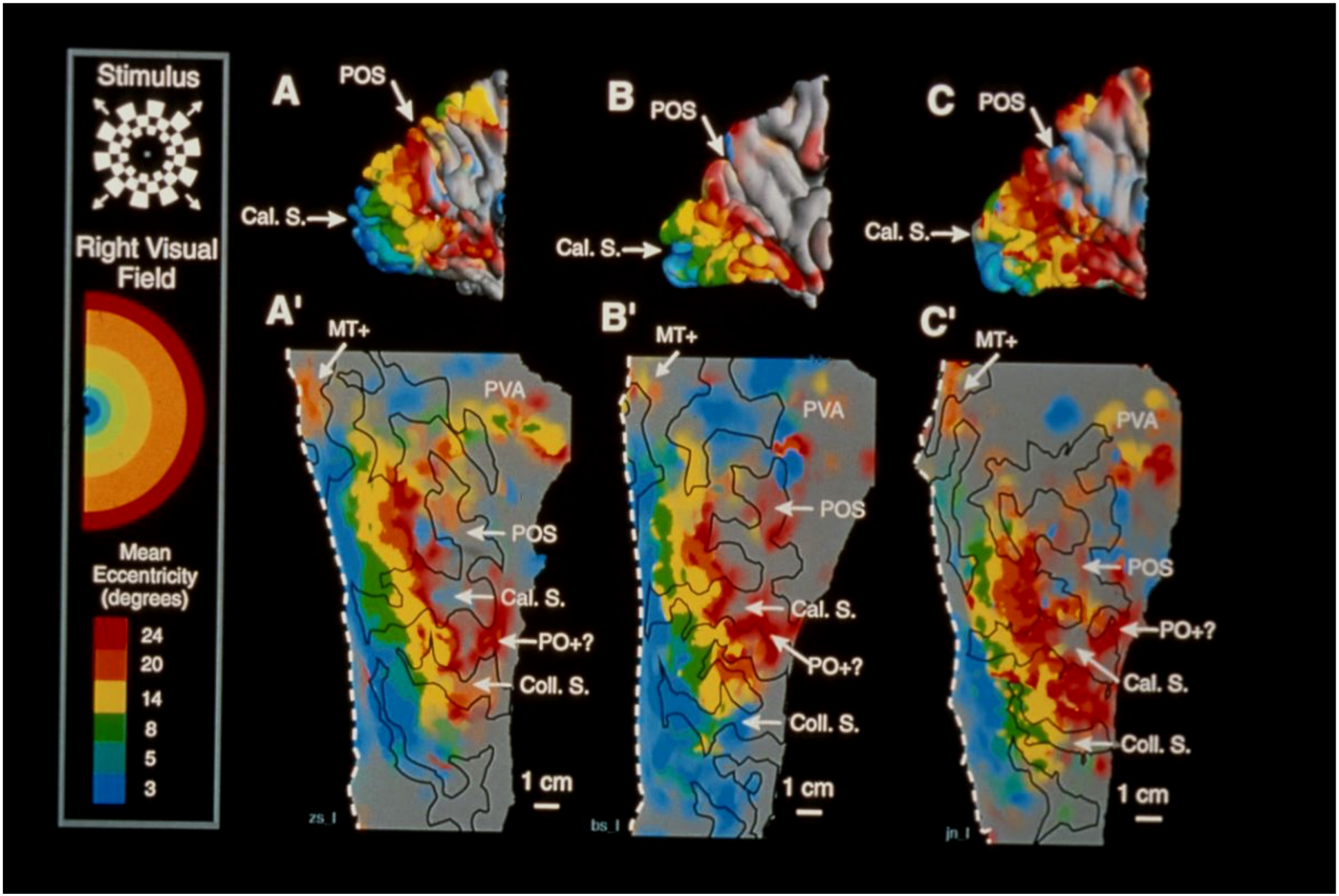
Proc. Natl. Acad. Sci. USA
Vol. 93, pp. 2382–2386, March 1996
Neurobiology

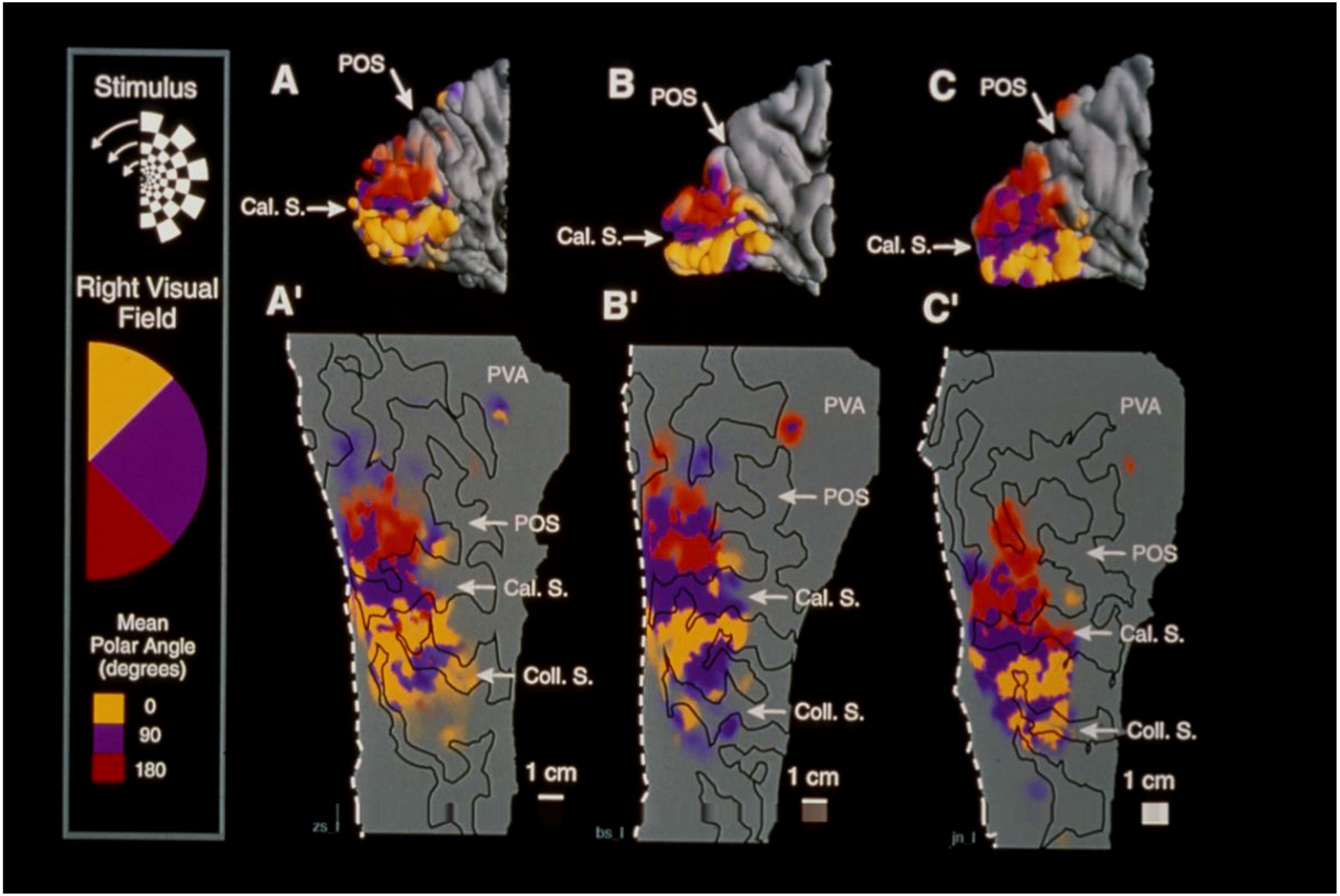
Mapping striate and extrastriate visual areas in human cerebral cortex

EDGAR A. DEYOE*, GEORGE J. CARMAN†, PETER BANDETTINI‡, SETH GLICKMAN*, JON WIESER*, ROBERT COX§, DAVID MILLER¶, AND JAY NEITZ*

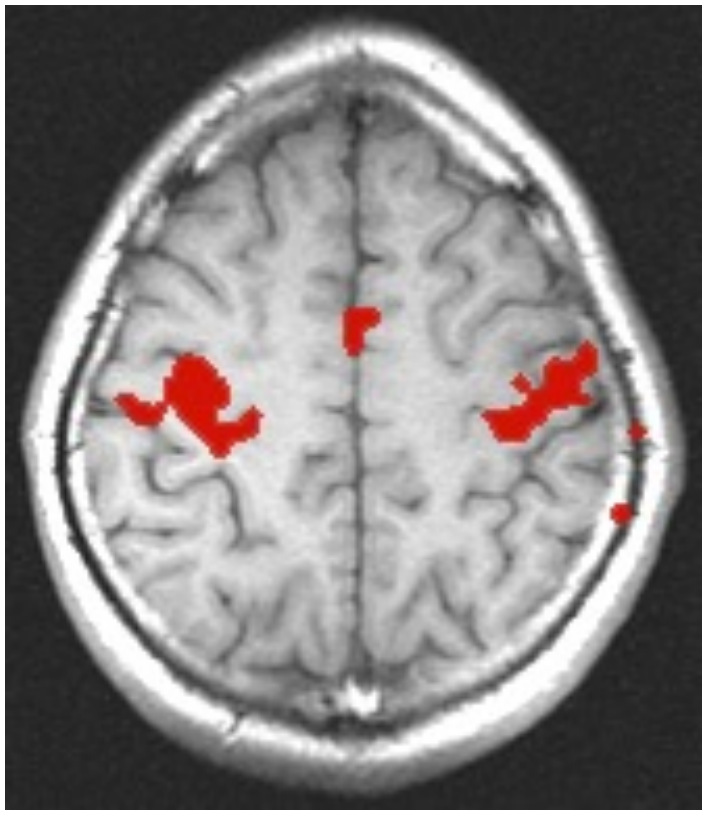
*Department of Cellular Biology and Anatomy, and Biophysics Research Institute, The Medical College of Wisconsin, 8701 Watertown Plank Road, Milwaukee, WI 53226; †The Salk Institute for Biological Studies, La Jolla, CA 92037; ‡Massachusetts General Hospital–NMR Center, Charlestown, MA 02129; §Biophysics Research Institute, The Medical College of Wisconsin, Milwaukee, WI 53226; and ¶Brown University, Providence, RI 02912

Communicated by Francis Crick, The Salk Institute for Biological Sciences, San Diego, CA, November 14, 1995 (received for review August 2, 1995)

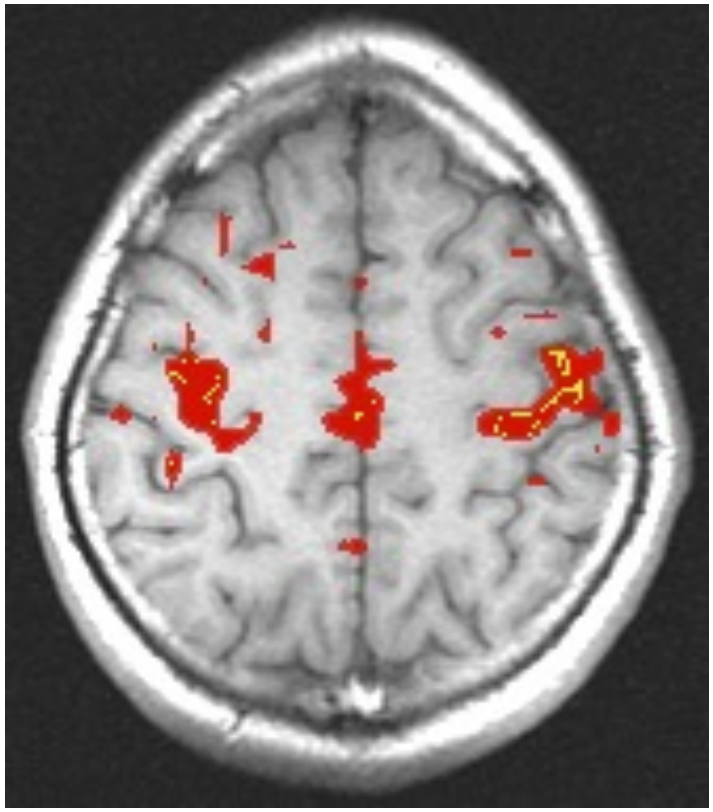

Stimulus
Right Visual Field
Mean Eccentricity (degrees)
24
20
14
8
5
3
A
POS
Cal. S.
B
POS
Cal. S.
C
POS
Cal. S.
A'
MT+
PVA
POS
Cal. S.
PO+?
Coll. S.
1 cm
zs_l
B'
MT+
PVA
POS
Cal. S.
PO+?
Coll. S.
1 cm
bs_l
C'
MT+
PVA
POS
PO+?
Cal. S.
Coll. S.
1 cm
jn_l


Stimulus
Right Visual Field
Mean Polar Angle (degrees)
0
90
180
A
POS
Cal. S.
B
POS
Cal. S.
C
POS
Cal. S.
A'
PVA
POS
Cal. S.
Coll. S.
1 cm
B'
PVA
POS
Cal. S.
Coll. S.
1 cm
C'
PVA
POS
Cal. S.
Coll. S.
1 cm

Resting State Correlations



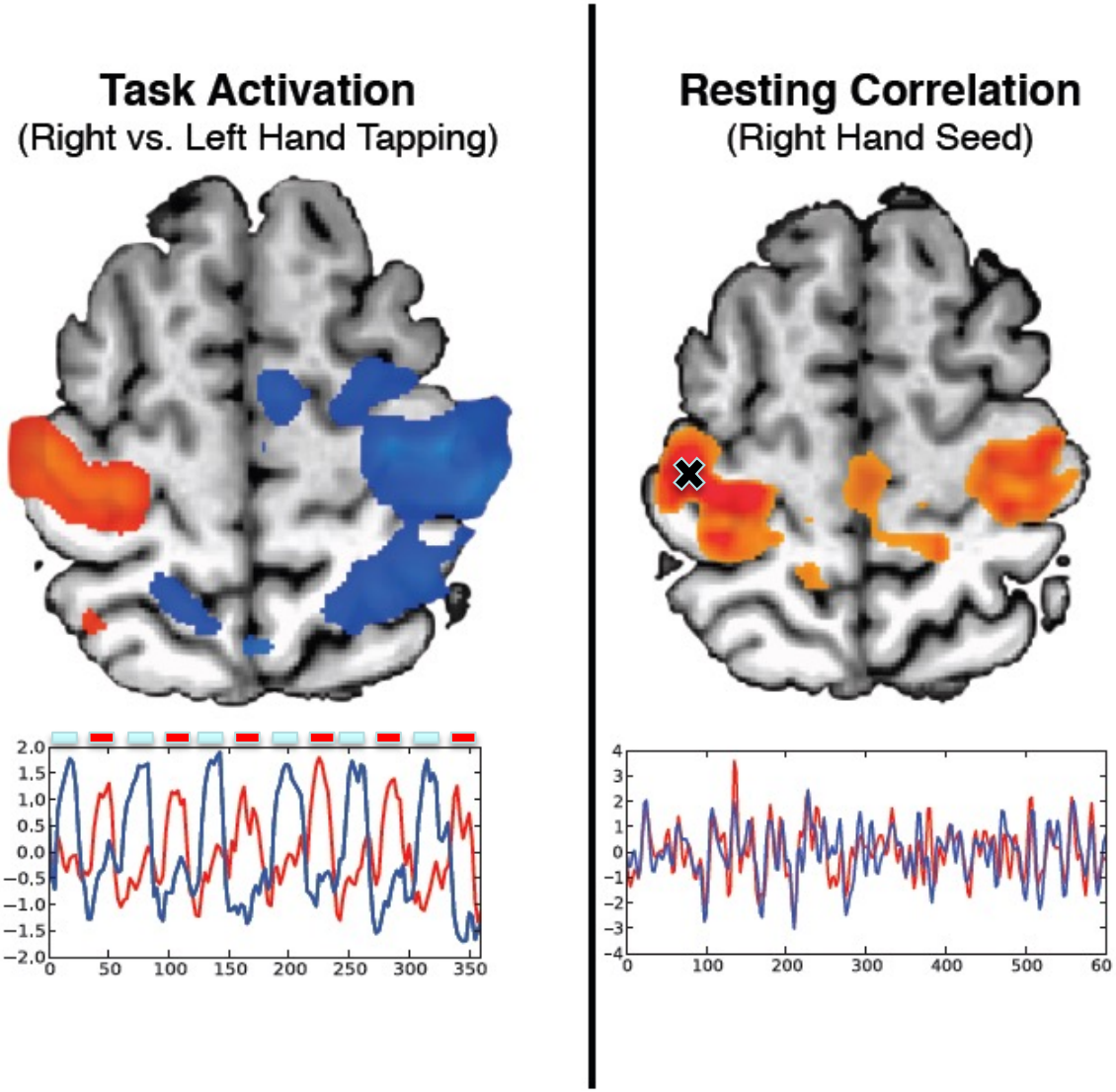
Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

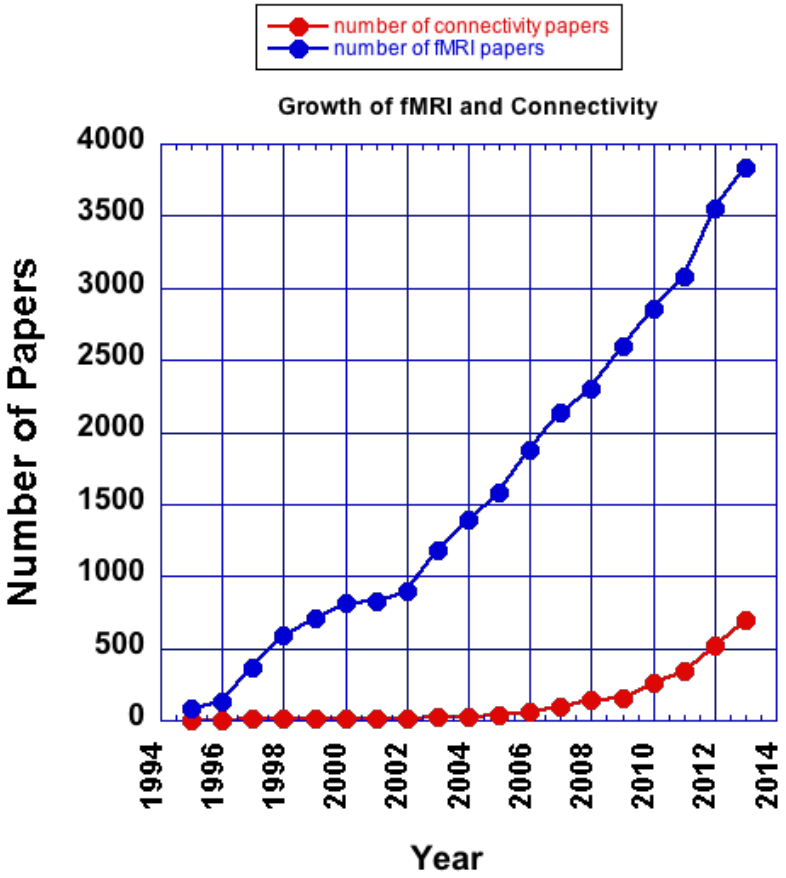
B. Biswal *et al.*, MRM, 34:537 (1995)

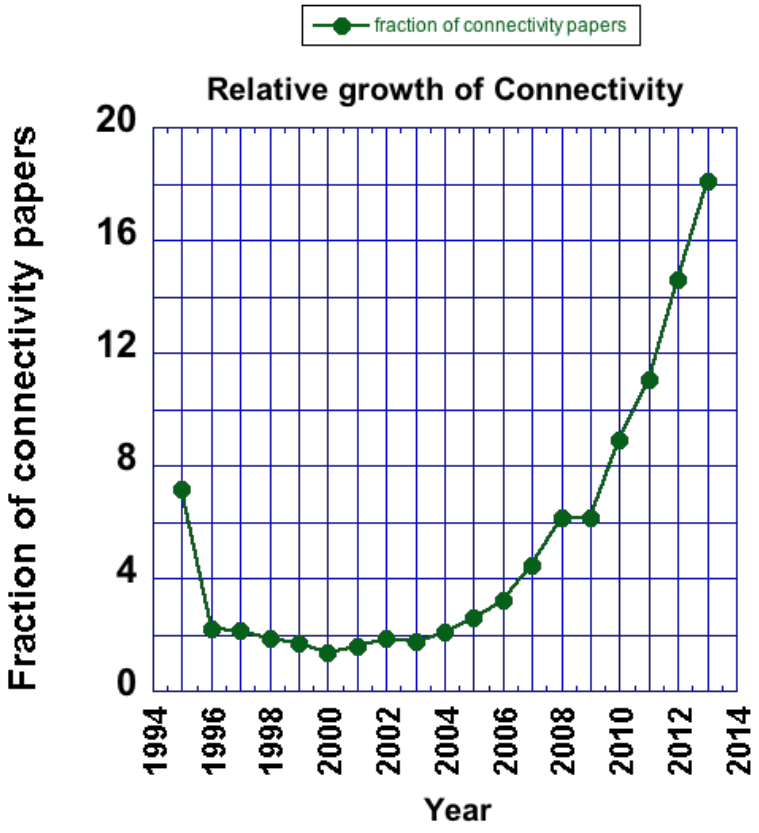
Activation-based fMRI and "resting state" f



Resting state fMRI: Why is this area important?

- The number of papers and applications has exploded.
- Neuronal, psychiatric, and developmental disorders may relate to altered connectivity.
- Methods are in their infancy, and rapidly evolving.
- Neuronal correlates of spontaneous fluctuations are not fully understood.



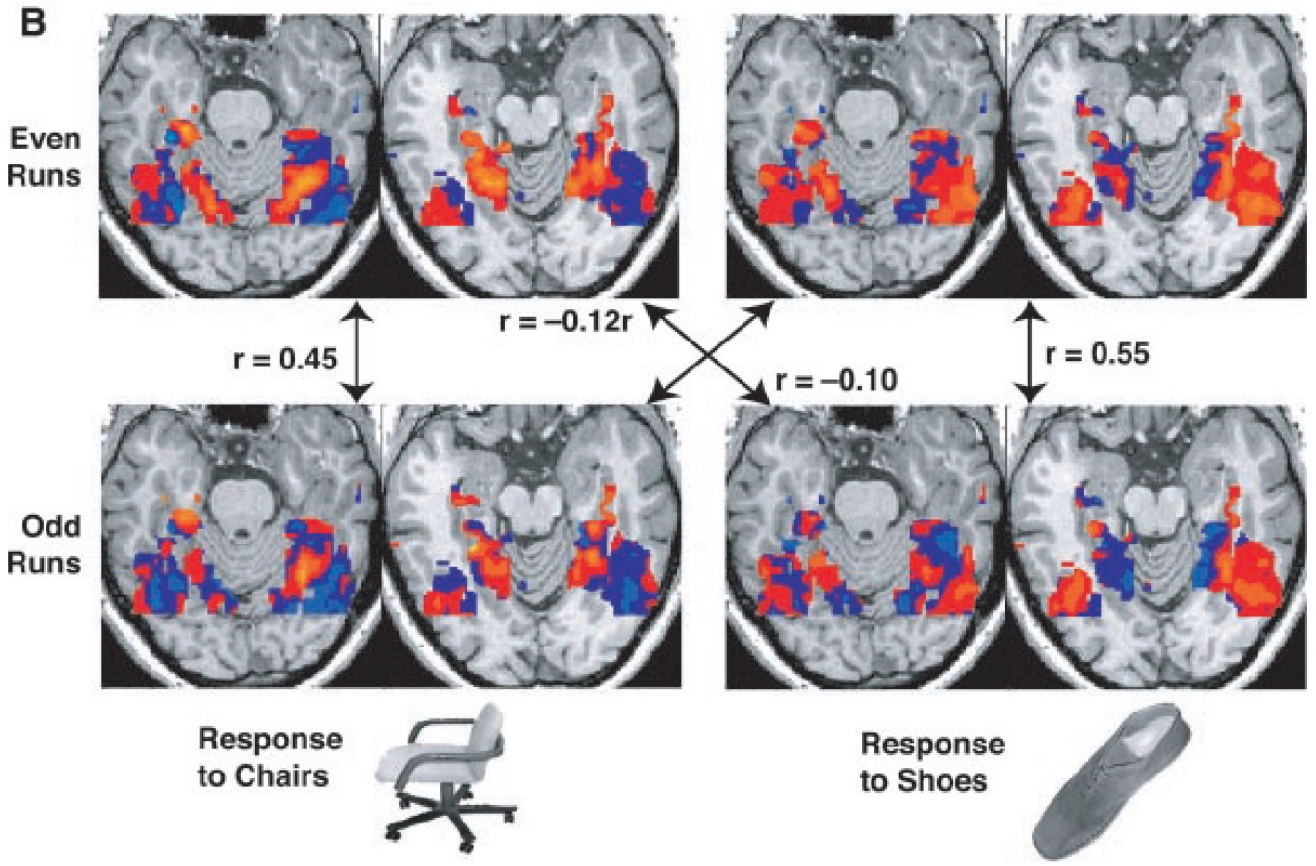


Magnetic Resonance in Medicine
“30 papers that shaped the field.”

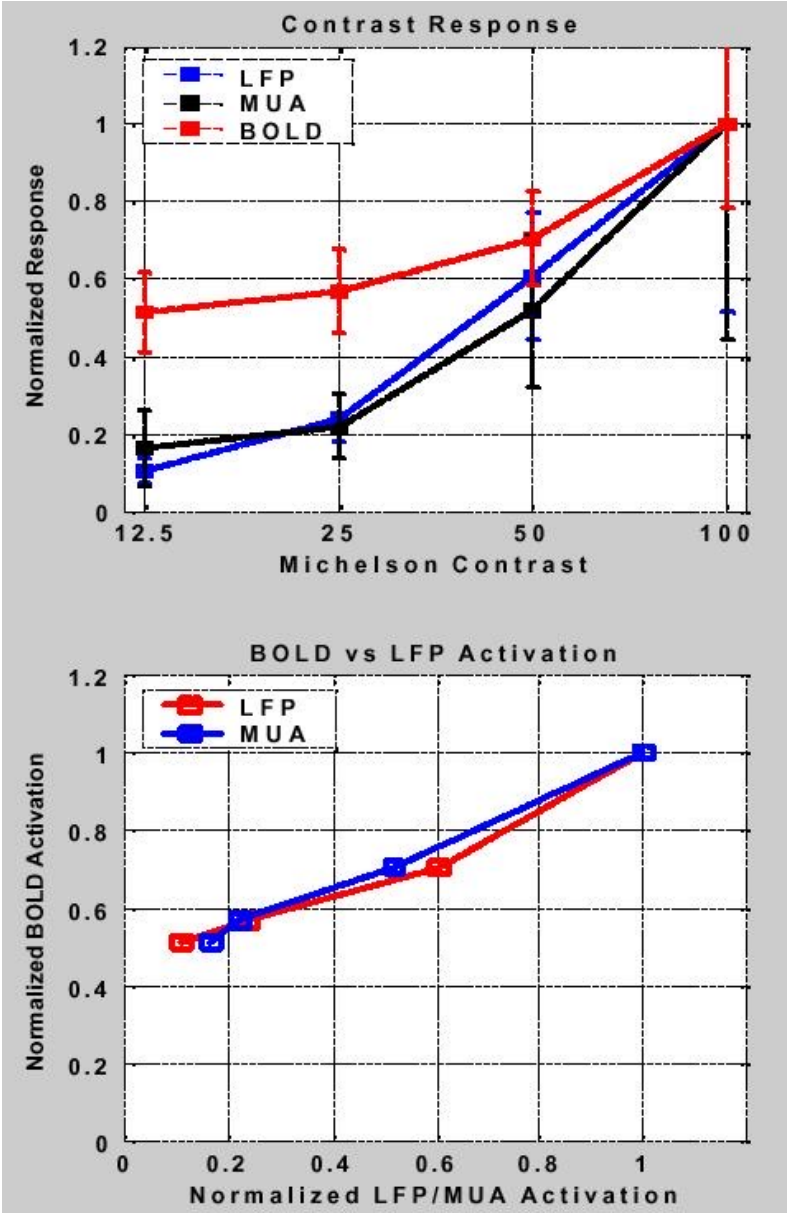
Distributed and Overlapping Representations of Faces and Objects in Ventral Temporal Cortex

James V. Haxby,[1]* M. Ida Gobbini,[1,2] Maura L. Furey,[1,2]
Alumit Ishai,[1] Jennifer L. Schouten,[1] Pietro Pietrini[3]

SCIENCE VOL 293 28 SEPTEMBER 2001



Logothetis et al. (2001) "Neurophysiological investigation of the basis of the fMRI signal" Nature, 412, 150-157



Parametric manipulation of brain activation demonstrated that BOLD contrast approximately followed the level of brain activation: visual system (Kwong et al., 1992), auditory system (Binder et al., 1994), and motor system (Rao et al., 1996).

The use of continuous variation of visual stimuli parameters as a function of time was proven a powerful method for fMRI-based retinotopy: (Engel et al., 1994, Deyoe et al., 1994, Sereno et al., 1995).

Event-related fMRI was first demonstrated (Blamire et al., 1992).

Application of event-related fMRI to cognitive activation was shown (Buckner et al., 1996, McCarthy et al., 1997).

Development of mixed event-related and block designs was put forward: (Donaldson et al., 2002).

Paradigms were demonstrated in which the activation timing of multiple brain systems timing was orthogonal, allowing multiple conditions to be cleanly extracted from a single run (Courtney et al., 1997).

High resolution maps were created: For spatial resolution: ocular dominance columns (Menon et al., 1997, Cheng et al., 2001) and cortical layer activation maps were created (Logothetis et al., 2002).

Extraction of information at high spatial frequencies within regions of activation was demonstrated (Haxby et al., 2001).

For temporal resolution: Timings from ms to hundreds of ms were extracted (Ogawa et al., 2000, Menon et al., 1998, Henson et al., 2002, Bellgowan et al., 2003).

The development of "deconvolution" methods allowed for rapid presentation of stimuli (Dale and Buckner, 1997).

Early BOLD contrast models were put forward: (Ogawa et al., 1993, Buxton and Frank, 1997).

More sophisticated models were published that more fully integrated the latest data on hemodynamic and metabolic changes (Buxton et al., 2004).

The development of "clustered volume" acquisition was put forth as a method to avoid scanner noise artifacts: (Edmister et al., 1999).

The findings of functionally related resting state correlations: (Biswal et al., 1995) and regions that consistently show deactivation (Binder et al., 1999, Raichle et al., 2001) were described.

Observation of the pre-undershoot in fMRI (Hennig et al., 1997, Menon et al., 1995, Hu et al., 1997) and correlation with optical imaging was reported (Malonek and Grinvald, 1996).

Simultaneous use of fMRI and direct electrophysiological recording in non-human primate brain during visual stimulation elucidated the relationship between fMRI and BOLD contrast. (Logothetis et al., 2001). Simultaneous electrophysiological recordings in animal models revealed a correlation between negative signal changes and decreased neuronal activity (Shmuel et al., 2002). Simultaneous electrophysiological recordings in animal models provided evidence that inhibitory input could cause an increase in cerebral blood flow (Matheiesen et al., 1998).