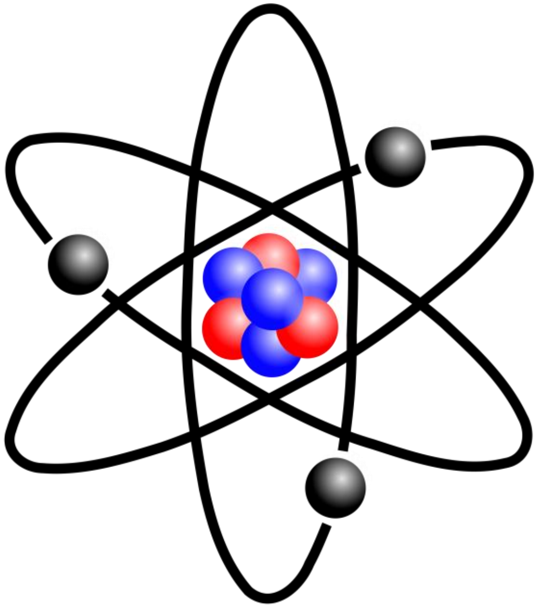
Physiological correlates of the BOLD signal
an Introduction

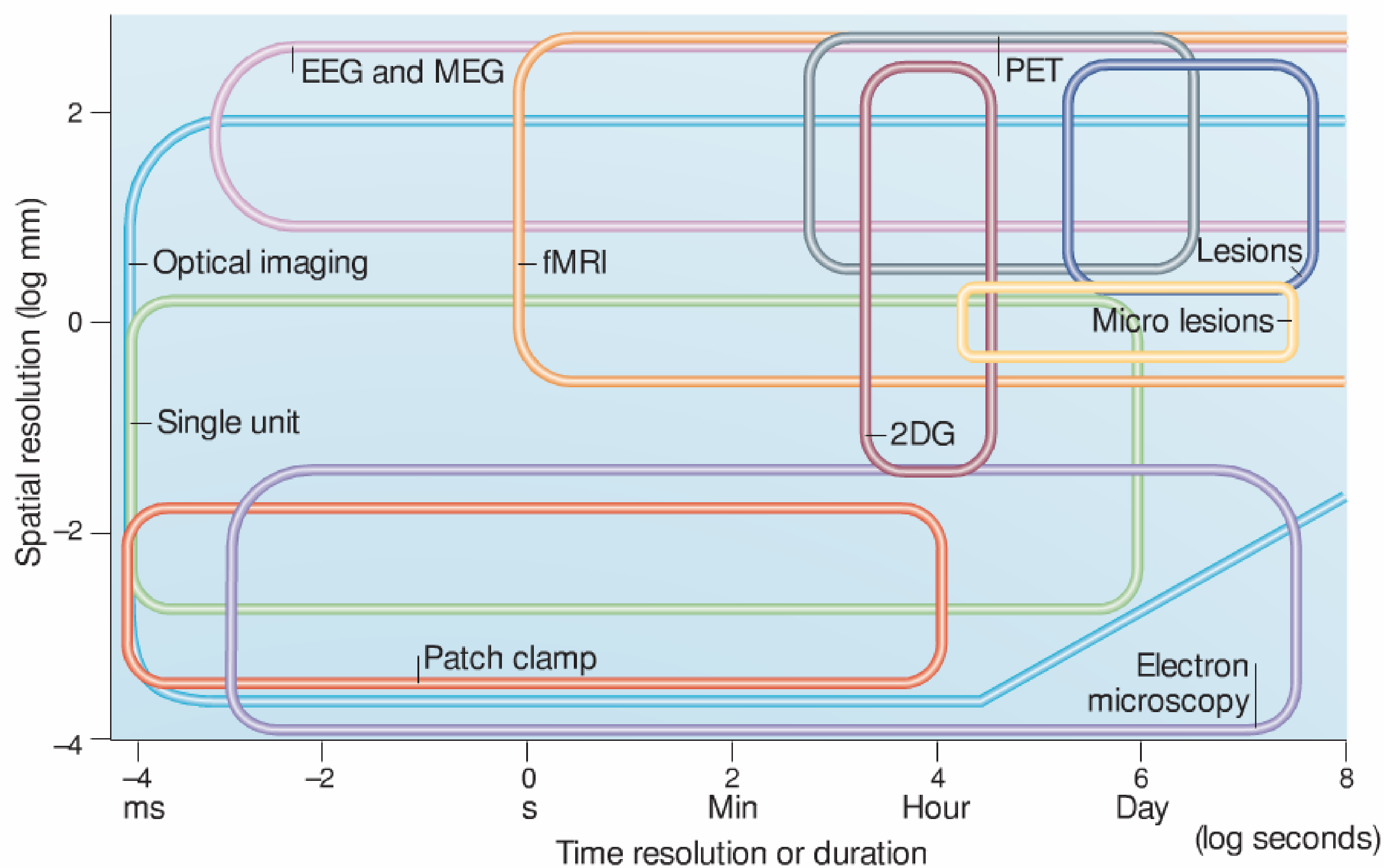
Goal

- To provide an oversimplified story on the physiological basis of BOLD signal

- To characterize BOLD & HRF

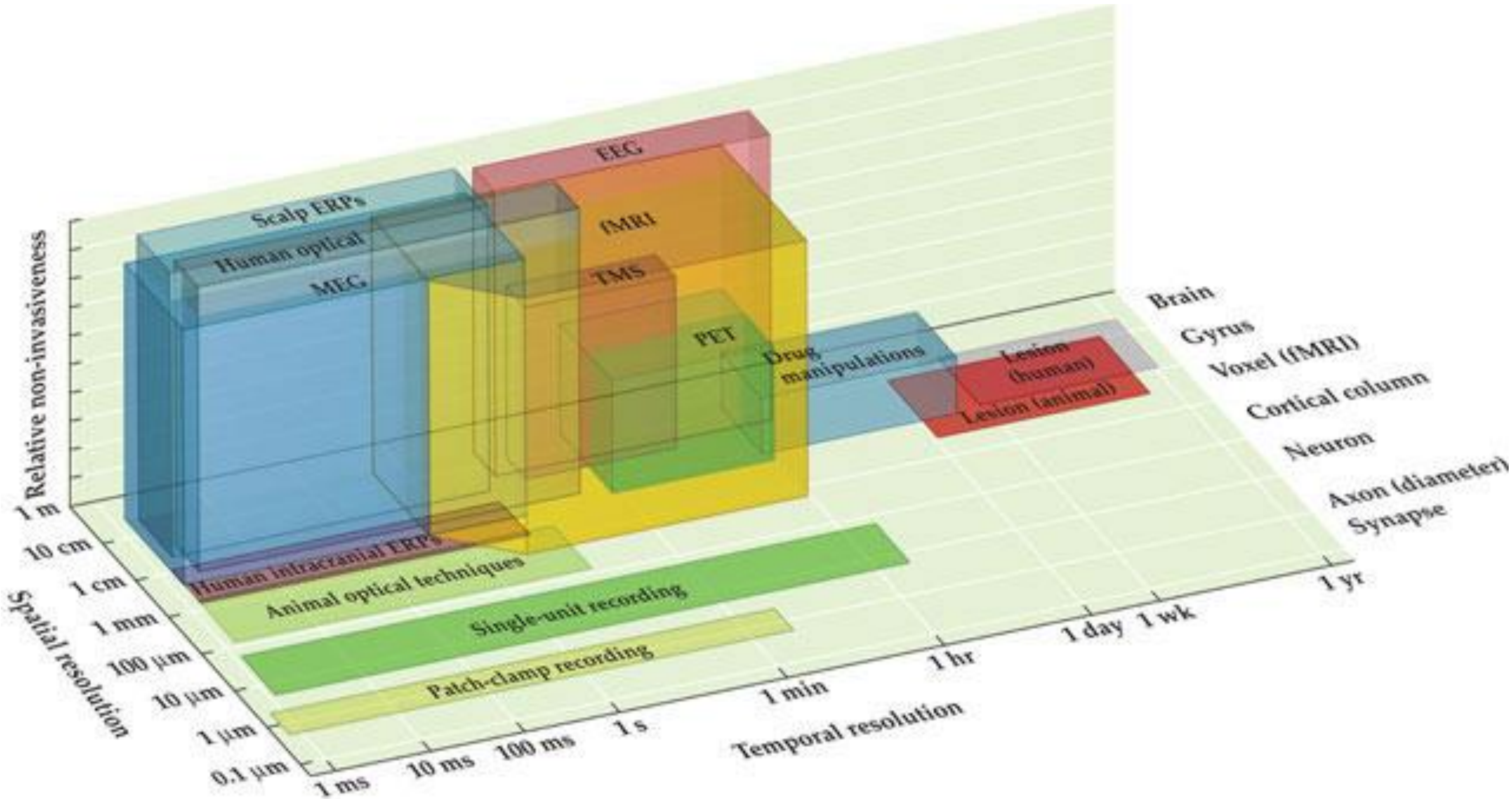


Modern functional brain mapping



(Grinvald & Hildesheim, 2004)

Modern functional brain mapping



(Grinvald & Hildesheim, 2004)

Functional Neuroimaging

JOURNAL OF NEUROPHYSIOLOGY
Vol. 51, No. 5, May 1984. *Printed in U.S.A.*

Stimulus Rate Dependence of Regional Cerebral Blood Flow in Human Striate Cortex, Demonstrated by Positron Emission Tomography

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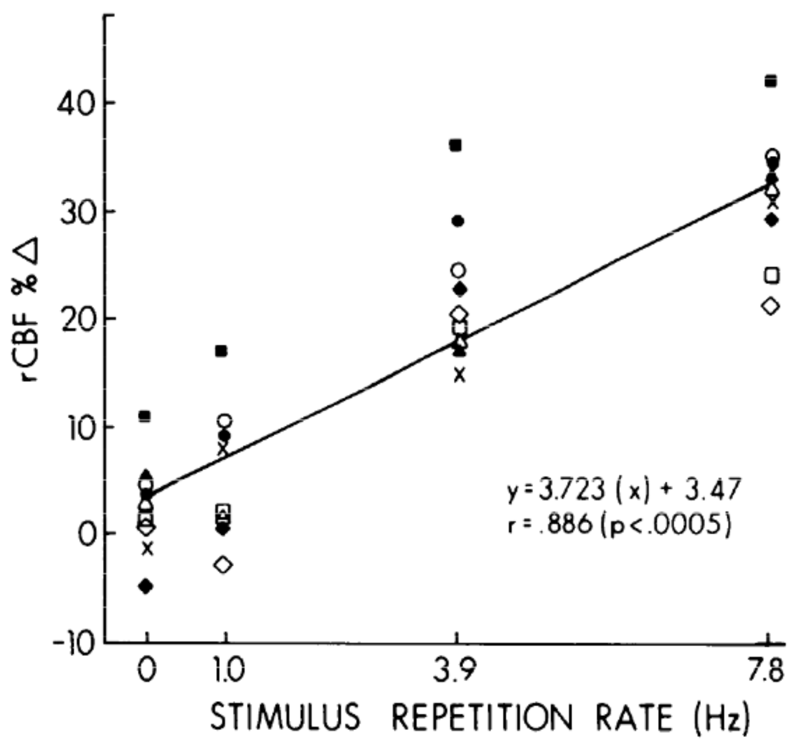
SUMMARY AND CONCLUSIONS

1. The purpose of this investigation was to determine the relationship between the repetition rate of a simple sensory stimulus and regional cerebral blood flow (rCBF) in the human brain

tween 0 and 7.8 Hz, rCBF%Δ was a linear function of stimulus repetition rate. The rCBF response peaked at 7.8 Hz and then declined. The rCBF%Δ during visual stimulation was significantly greater than that during visual deprivation for every stimulus rate except

Functional Neuroimaging

- Regional Cerebral Blood Flow (rCBF)
  - ⇧Neuronal activities
  - ⇧energy demand
  - ⇧rCBF



- rCBF varies with sensory stimulation frequency

Functional Neuroimaging

- fMRI – the story begins…

Proc. Natl. Acad. Sci. USA
Vol. 89, pp. 5675–5679, June 1992
Neurobiology

Dynamic magnetic resonance imaging of human brain activity during primary sensory stimulation

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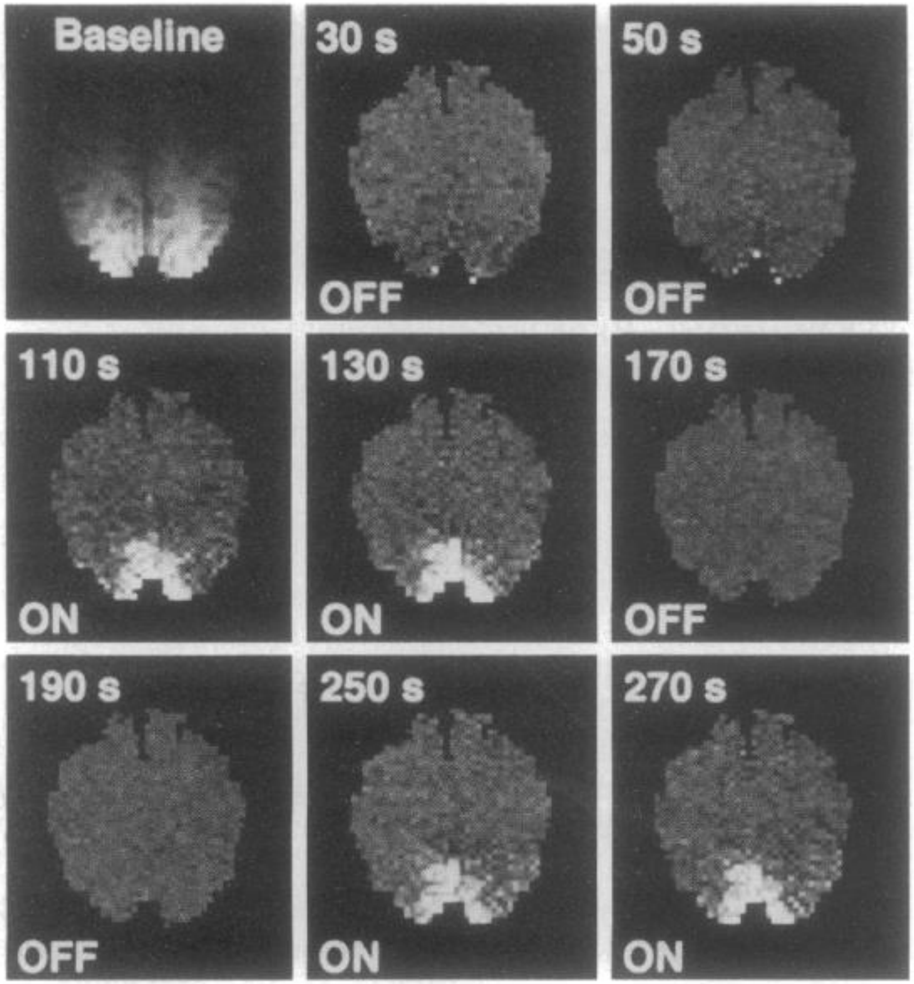
Communicated by David H. Hubel, March 26, 1992

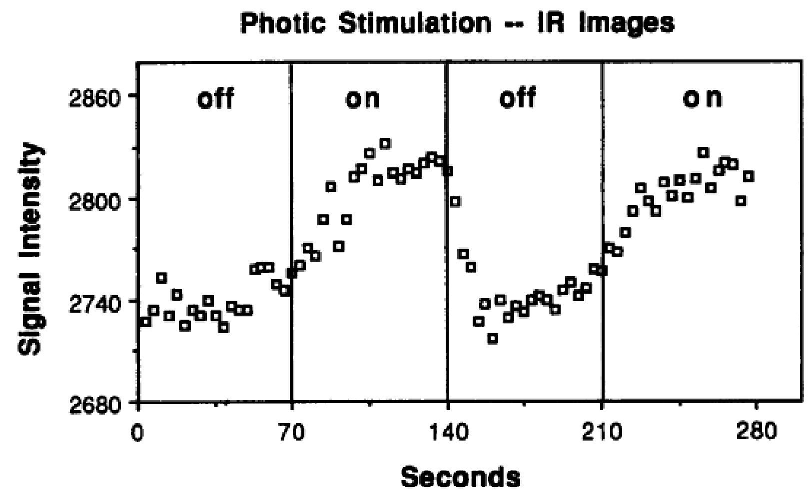
ABSTRACT **Neuronal activity causes local changes in cerebral blood flow, blood volume, and blood oxygenation. Magnetic resonance imaging (MRI) techniques sensitive to**

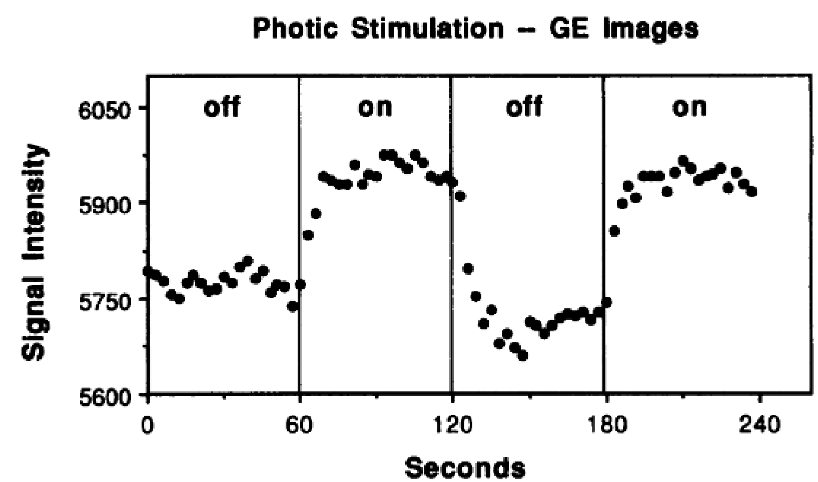
niques sensitive to these relaxation phenomena can thus be used to generate tomographic images of brain activity (17).

We report here completely noninvasive MRI of brain

Functional Neuroimaging

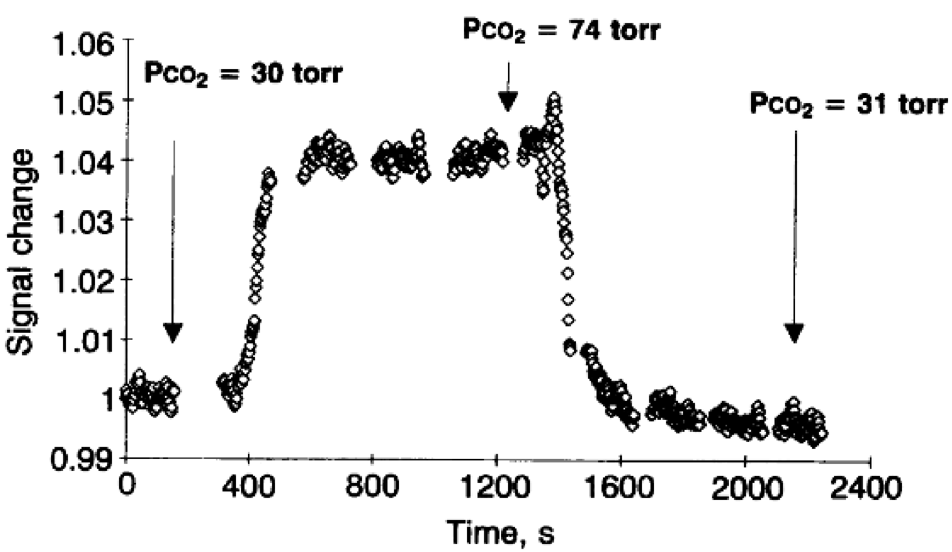


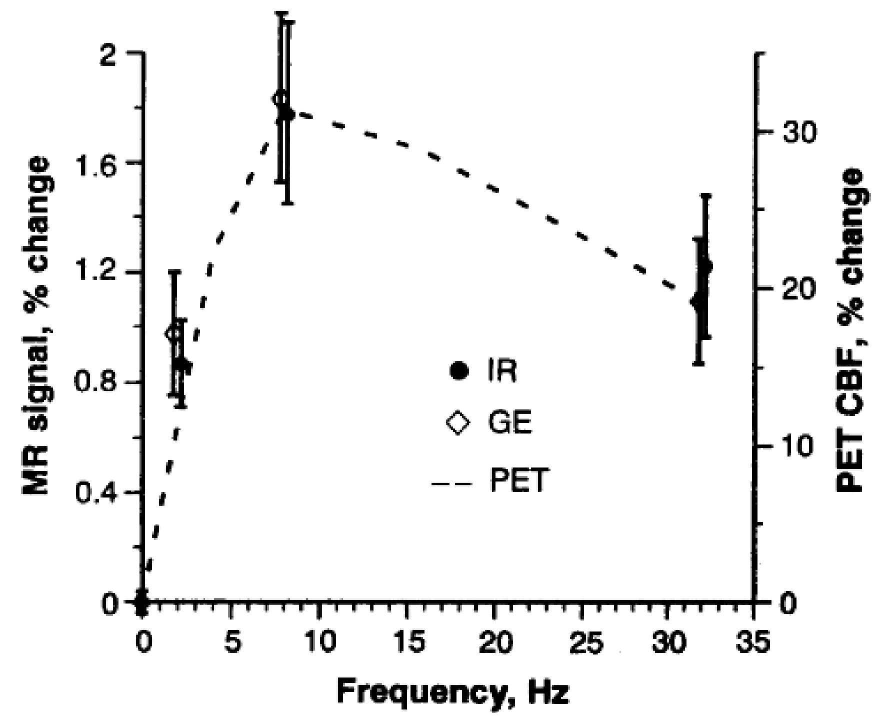




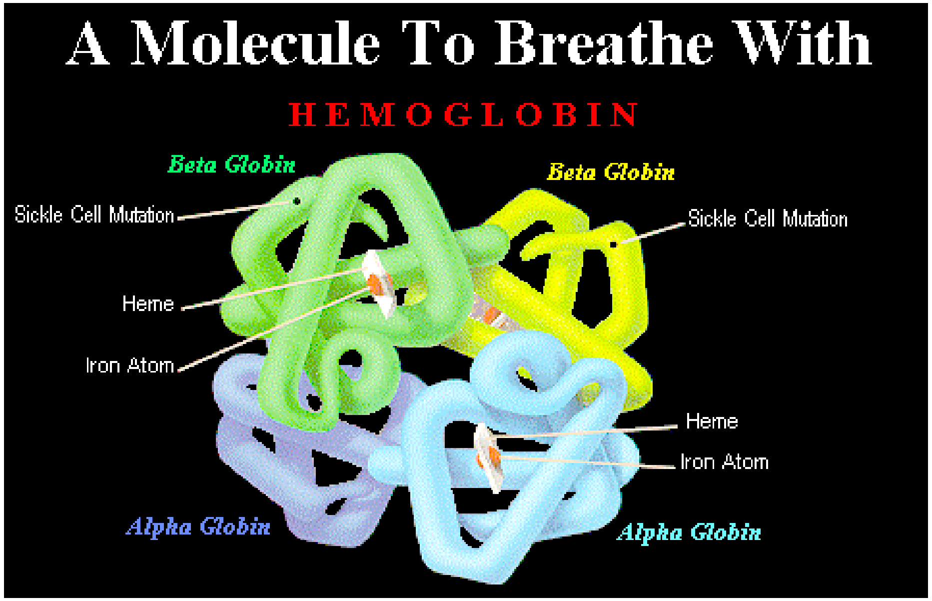
Functional Neuroimaging

- Functional MRI





Hemoglobin



Hemoglogin (is the iron-containing oxygen-transport metalloprotein in the red blood cells of all vertebrates):

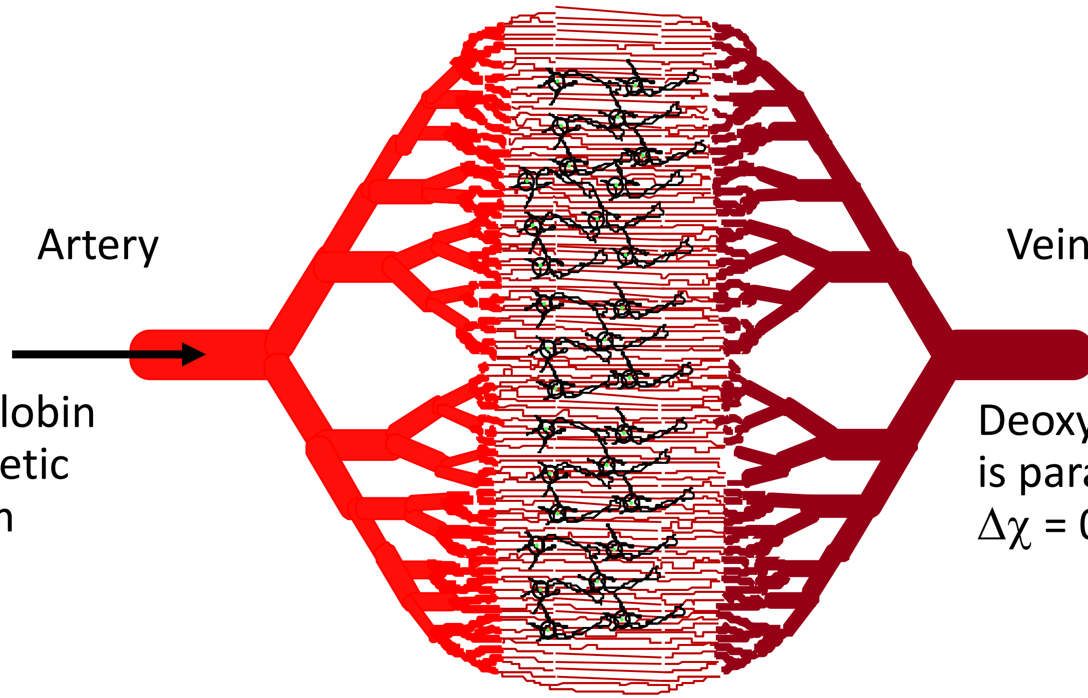
- four globin chains
  - each globin chain contains a heme group
  - at center of each heme group is an iron atom (Fe)
  - each heme group can attach two oxygen atoms (O_2)
  - oxy-Hgb (HBO_2 four x O_2) is diamagnetic
  - deoxy-Hgb (HBr) is paramagnetic

Source: http://wsrv.clas.virginia.edu/~rjh9u/hemoglob.html, Jorge Jovicich

The BOLD effect

Artery

Vein

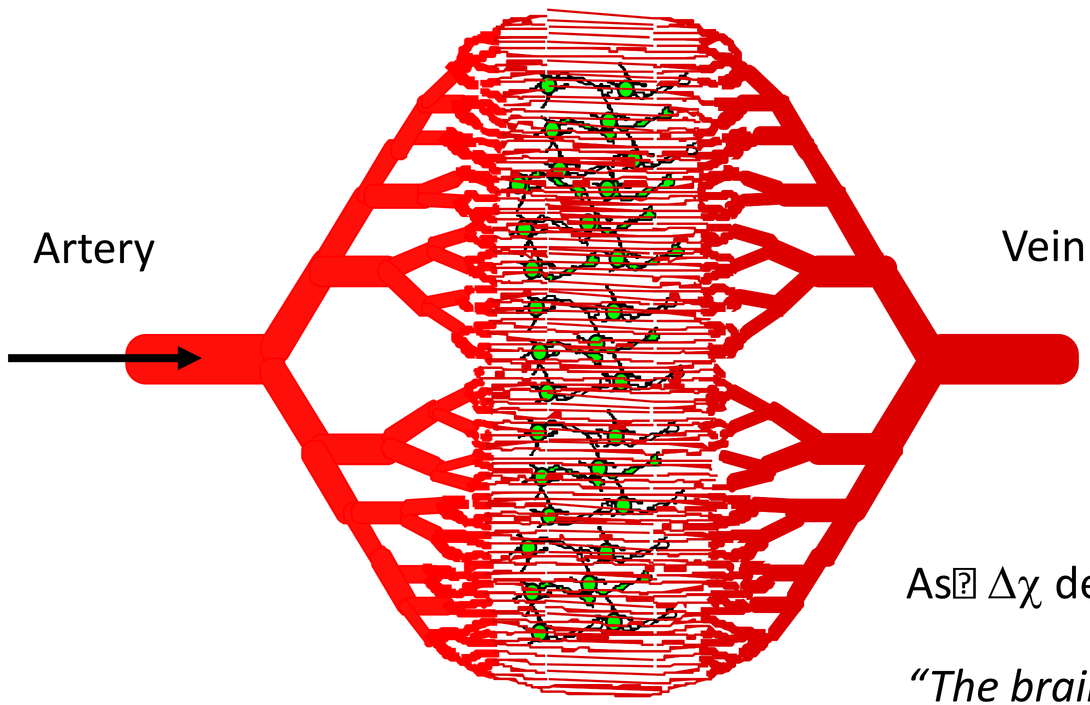


Oxyhemoglobin
is diamagnetic
$\Delta\chi = 0$ ppm

Deoxyhemoglobin
is paramagnetic
$\Delta\chi = 0.08$ ppm

Water protons (spin 1/2) sense these field shifts
which can be measured with the appropriate type of MRI.

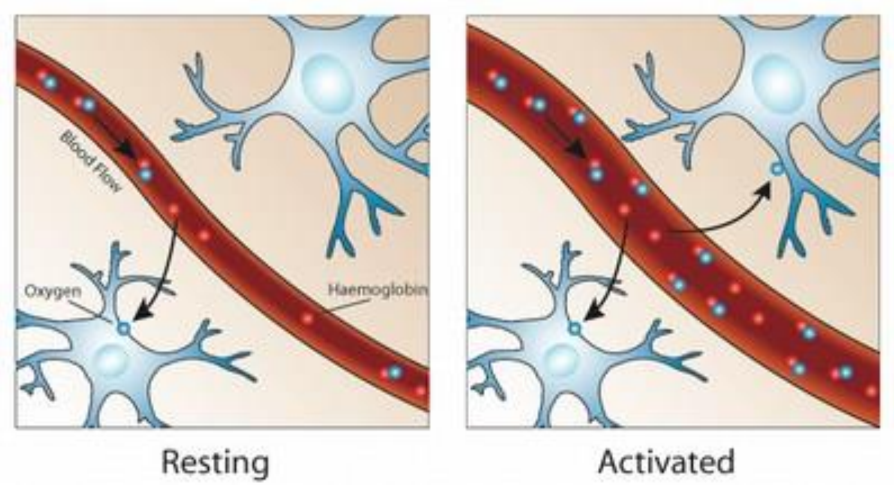
The BOLD effect



As $\Delta\chi$ decreases,

“The brain blushes”
Wilder Penfield

The BOLD effect



Hemoglobin is *diamagnetic when oxygenated* but *paramagnetic when deoxygenated*. This difference in magnetic properties leads to small differences in the MR signal of blood depending on the degree of oxygenation.

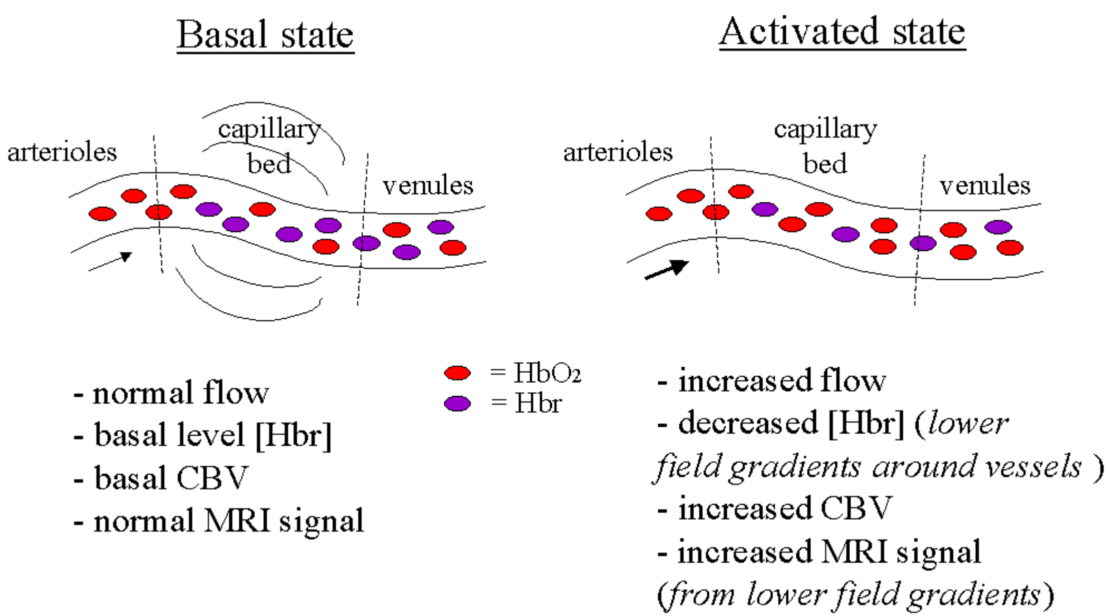
Since blood oxygenation varies according to the levels of neural activity these differences can be used to detect brain activity.

This form of MRI is known as **blood oxygenation level dependent (BOLD)** imaging.

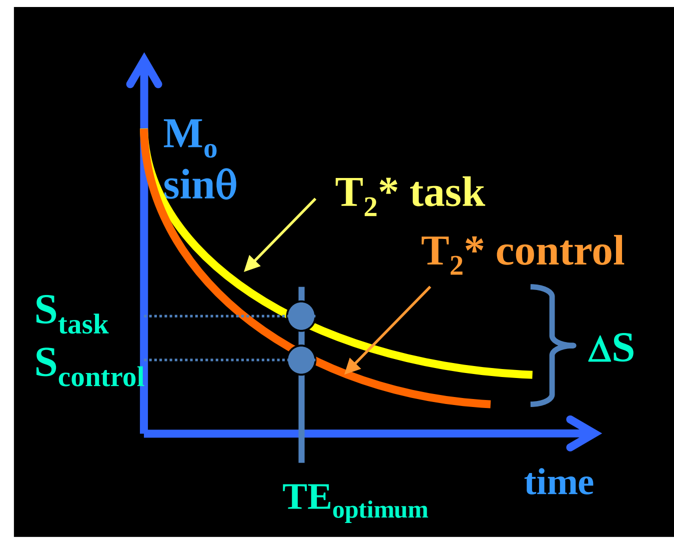
The BOLD signal

Blood Oxygen Level Dependent signal

↑neural activity ➔ ↑ blood flow ➔ ↑ oxyhemoglobin ➔ ↑ T2* ➔ ↑ MR signal

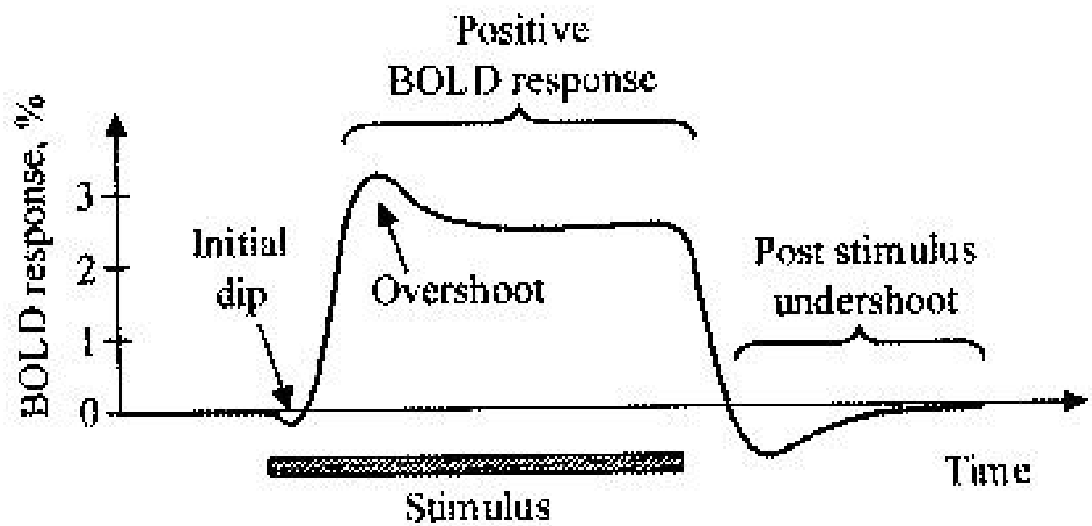


Source: [fMRIB Brief Introduction to fMRI]



Source: Jorge Jovicich

Hemodynamic Response Function (HRF)



% signal change

= (point – baseline)/baseline

usually 0.5-3%

initial dip

-more focal and potentially a better measure

-somewhat elusive so far, not everyone can find it

time to rise

signal begins to rise soon after stimulus begins

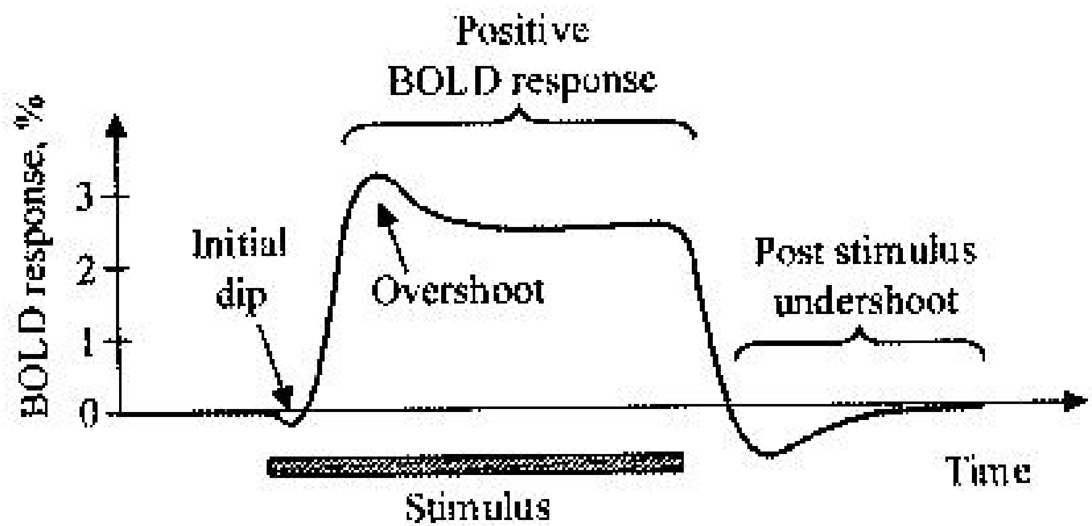
time to peak

signal peaks 4-6 sec after stimulus begins

post stimulus undershoot

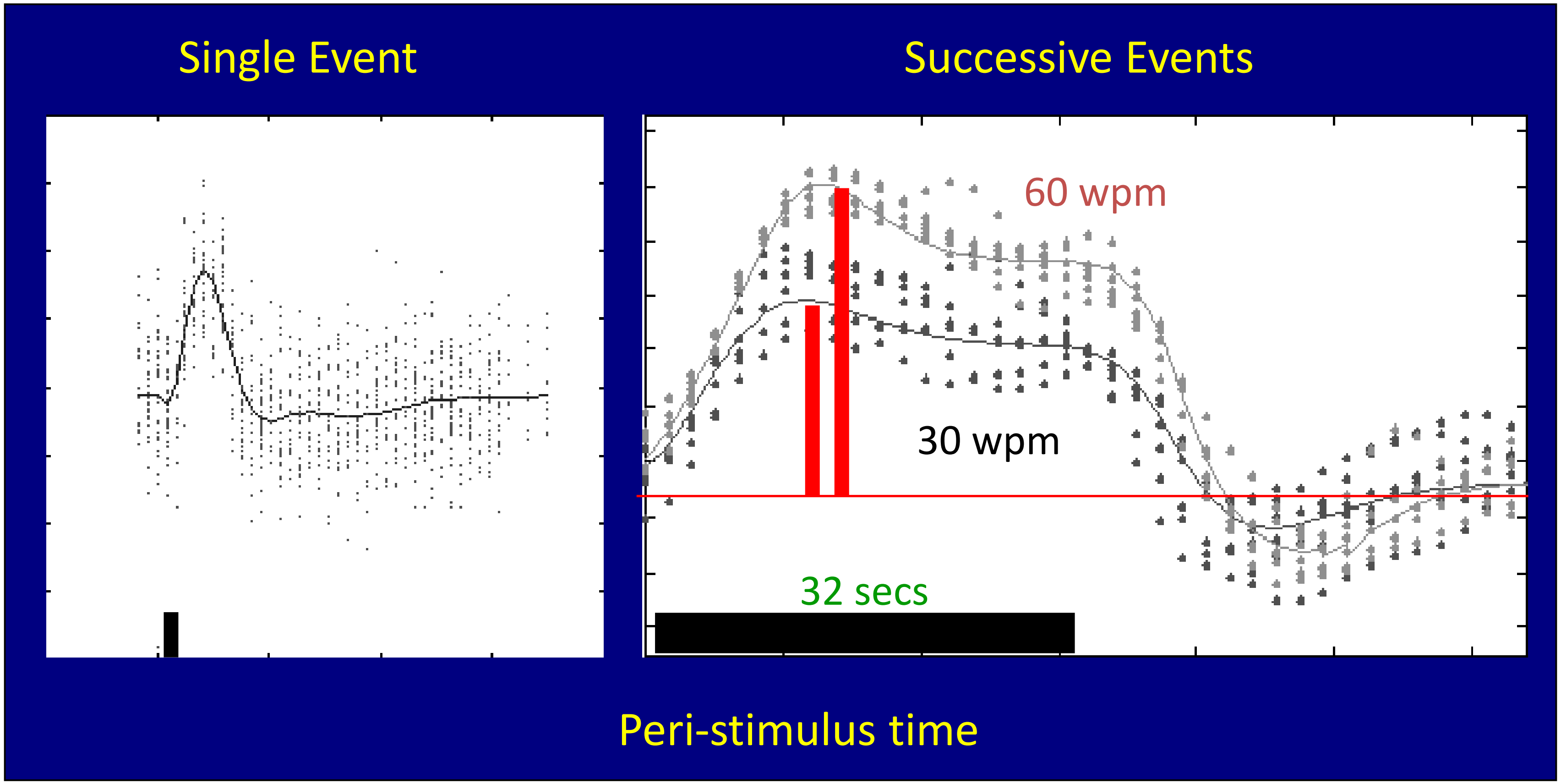
signal suppressed after stimulation ends

Hemodynamic Response Function (HRF)



There is a momentary decrease in blood oxygenation immediately after neural activity increases, known as the “initial dip” in the hemodynamic response.
This is followed by a period where the blood flow increases, not just to a level where oxygen demand is met, but overcompensating for the increased demand.
This means the blood oxygenation actually increases following neural activation.
The blood flow peaks after around 6 seconds and then falls back to baseline, often accompanied by a “post-stimulus undershoot”.

Hemodynamic Response Function (HRF)



Summary

- The BOLD signal…
  - is an <u>indirect</u> measure of rCBF
  - is the result of chain reactions associated with elevated energy consumption at the neuronal level
  - is limited by neural vasculature/blood perfusion
  - has a low SNR
  - is not the <u>only</u> way to perform fMRI, e.g. ASL

Summary

- The HRF…
  - is slow & spanning across several seconds
  - takes 4-6 secs to peak
  - seems to be additive
  - is empirically derived from (mainly) the sensory cortices