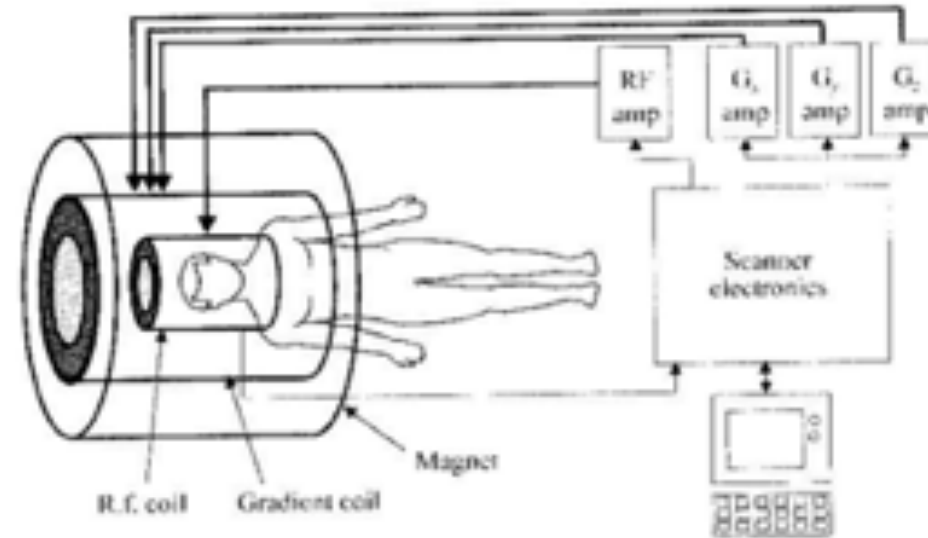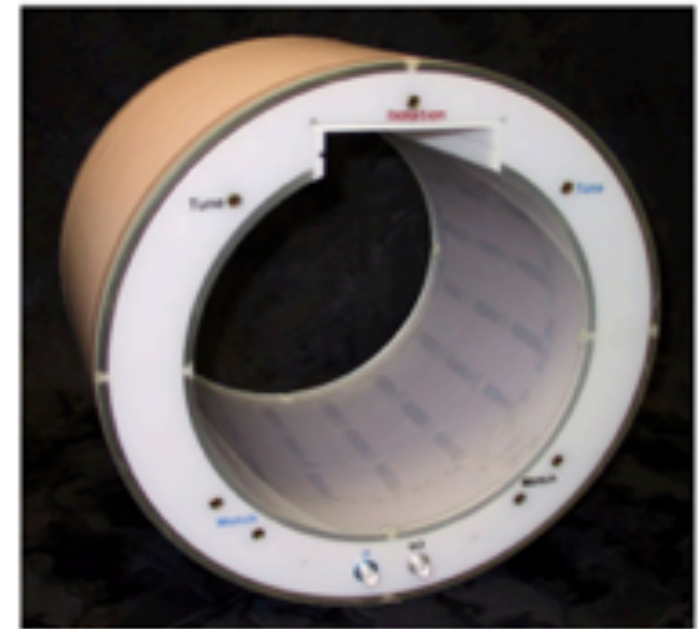# Measurement & Signal

Luke Chang
Dartmouth College

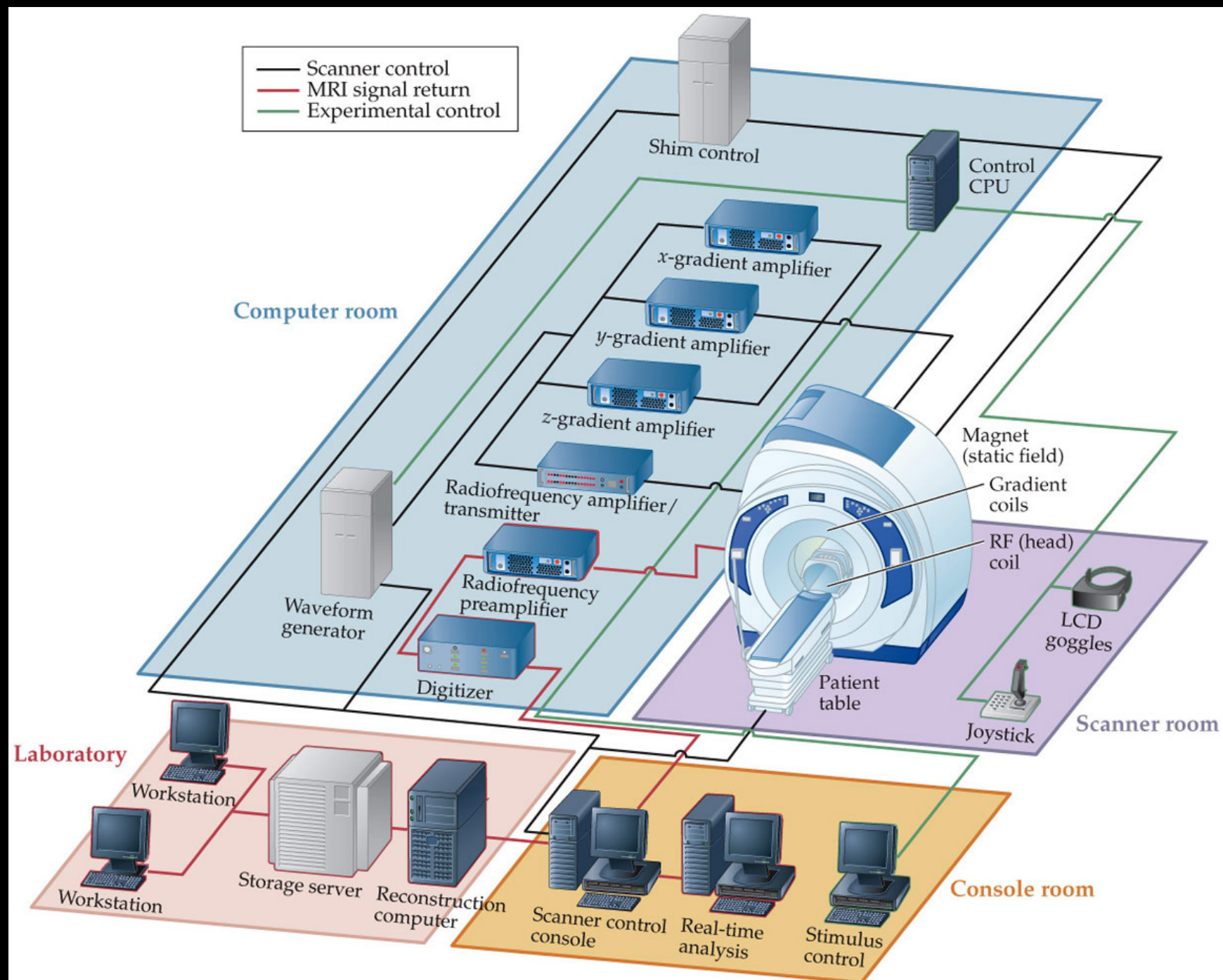# How does the scanner work?

# How does the scanner work?



- Step 1: Place an object/subject in a big magnet
- Step 2: Apply radio waves
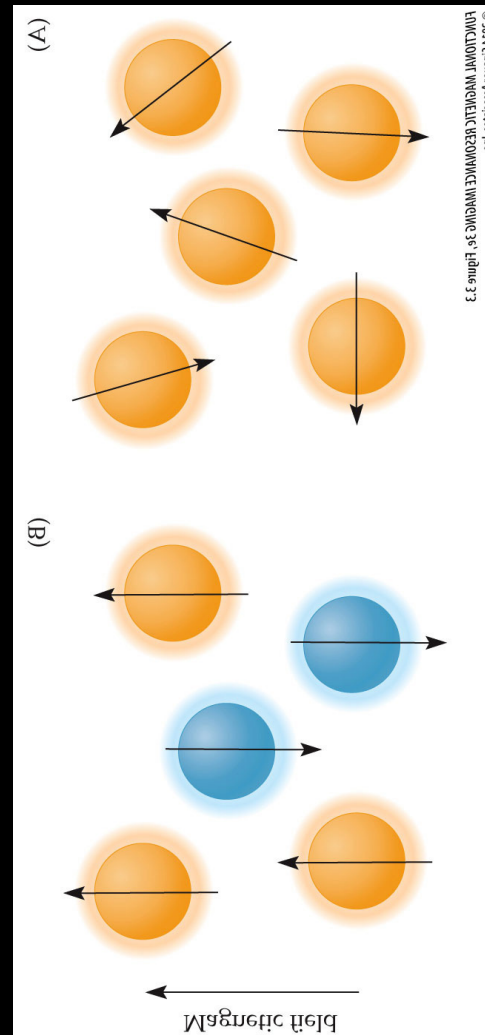- Step 3: Measure emitted radio waves

# fMRI Components



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 2.2
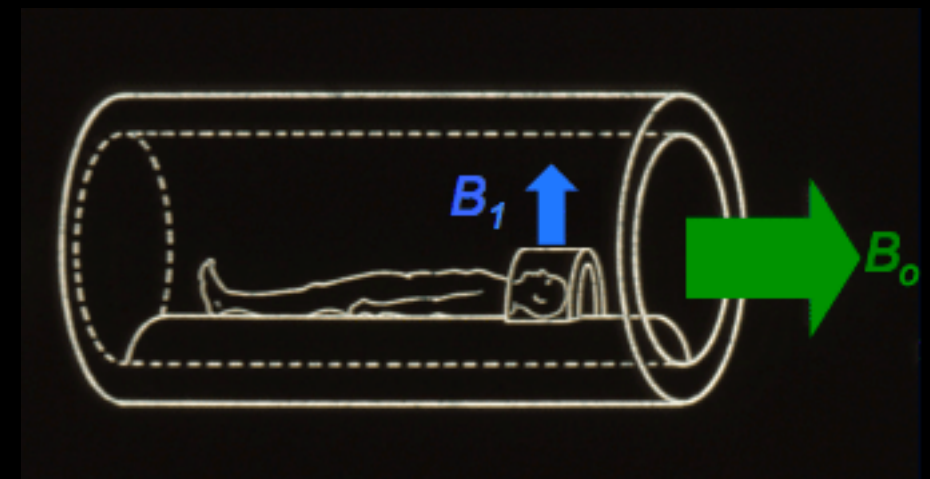© 2014 Sinauer Associates, Inc.

# Magnetic fields align hydrogen protons


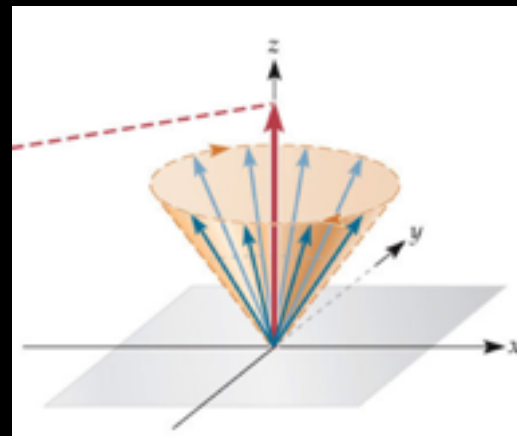
Body is composed of 70% water
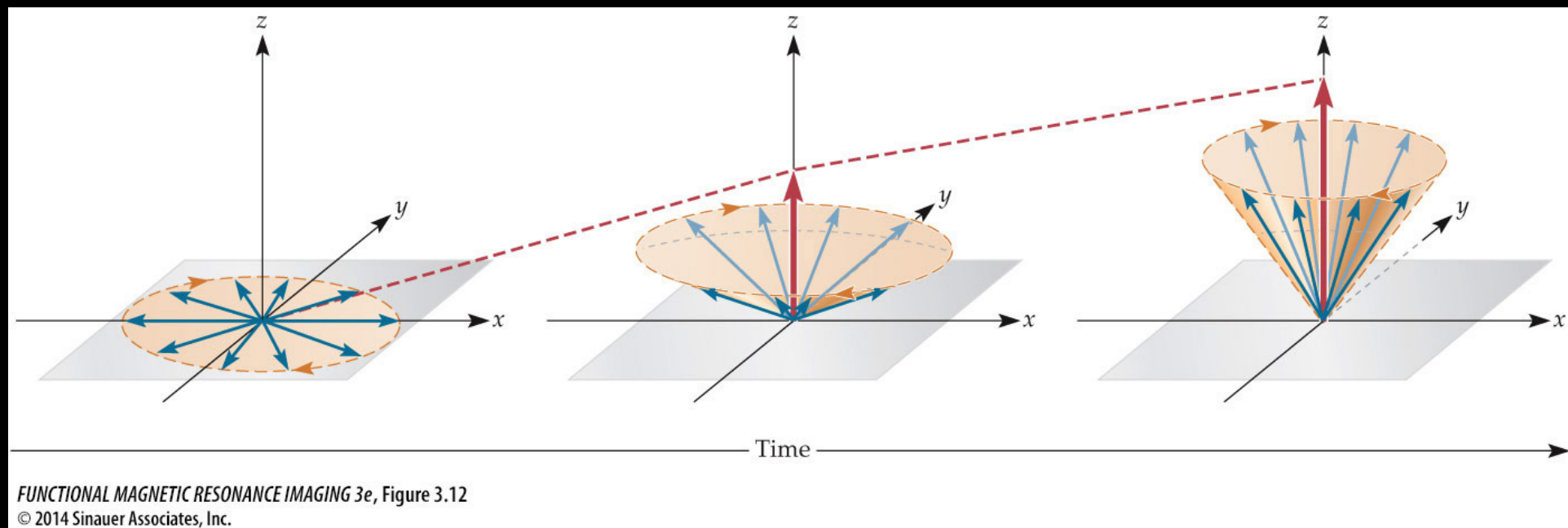


Magnetic field
Aligns hydrogen protons



MRI machines have two primary gradients of magnetic
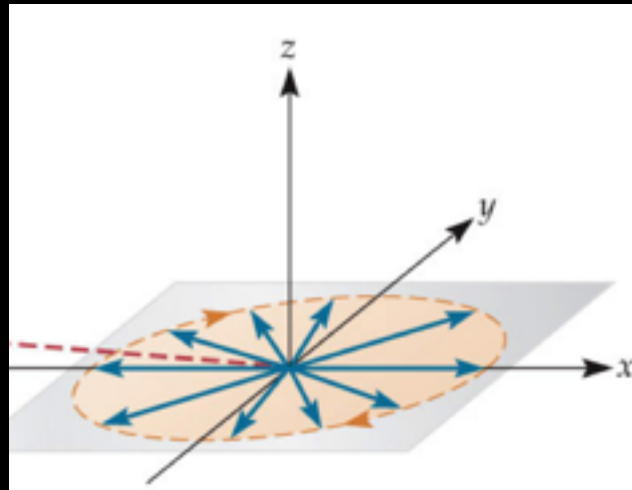
# T1 Relaxation/Recovery

Before RF Pulse



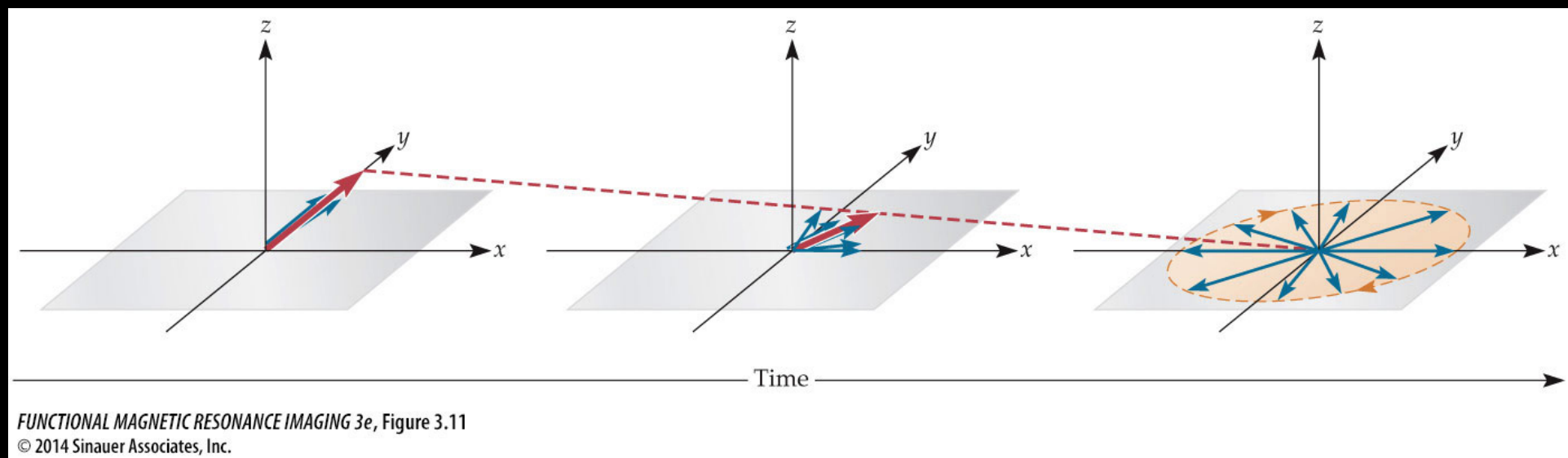After RF Pulse



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 3.12
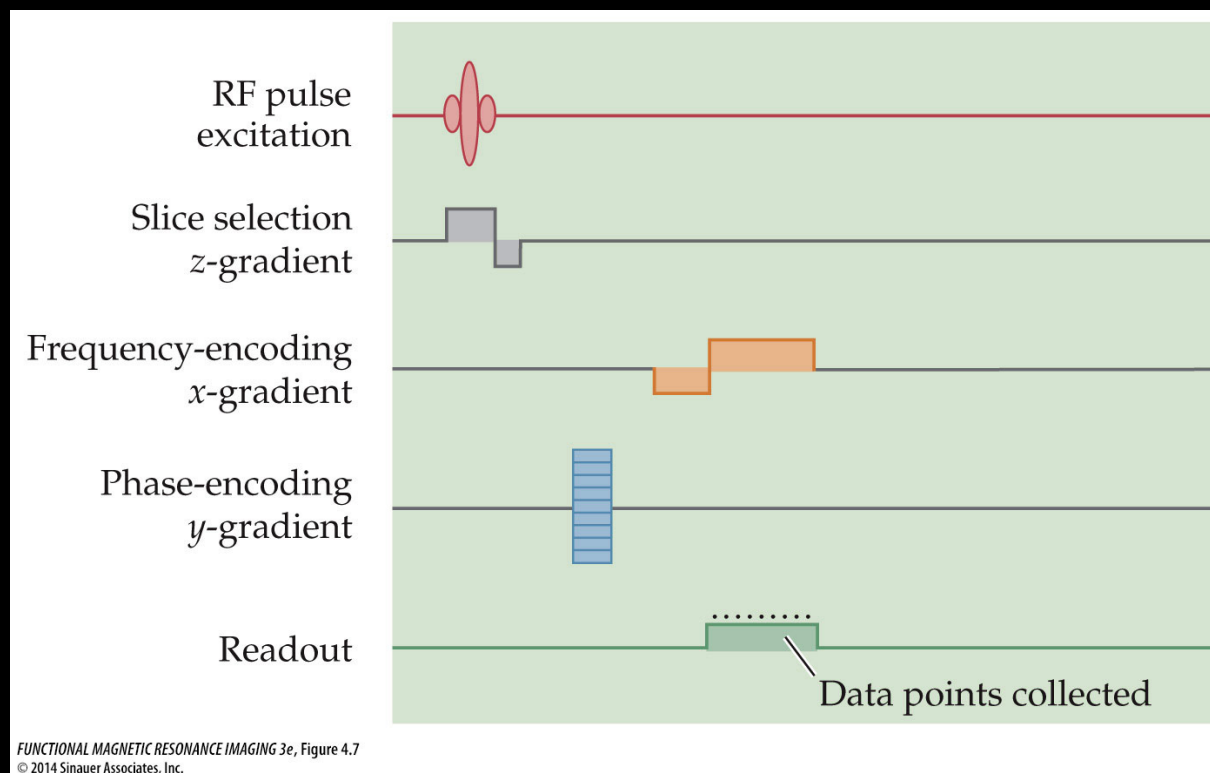© 2014 Sinauer Associates, Inc.

# T2 Decay

Before RF Pulse



After RF Pulse



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 3.11
© 2014 Sinauer Associates, Inc.

# RF pulse sequence for frequency and phase within a slice



RF pulse excitation

Slice selection z-gradient

Frequency-encoding x-gradient

Phase-encoding y-gradient

Readout

Data points collected

z-gradient

y-gradient
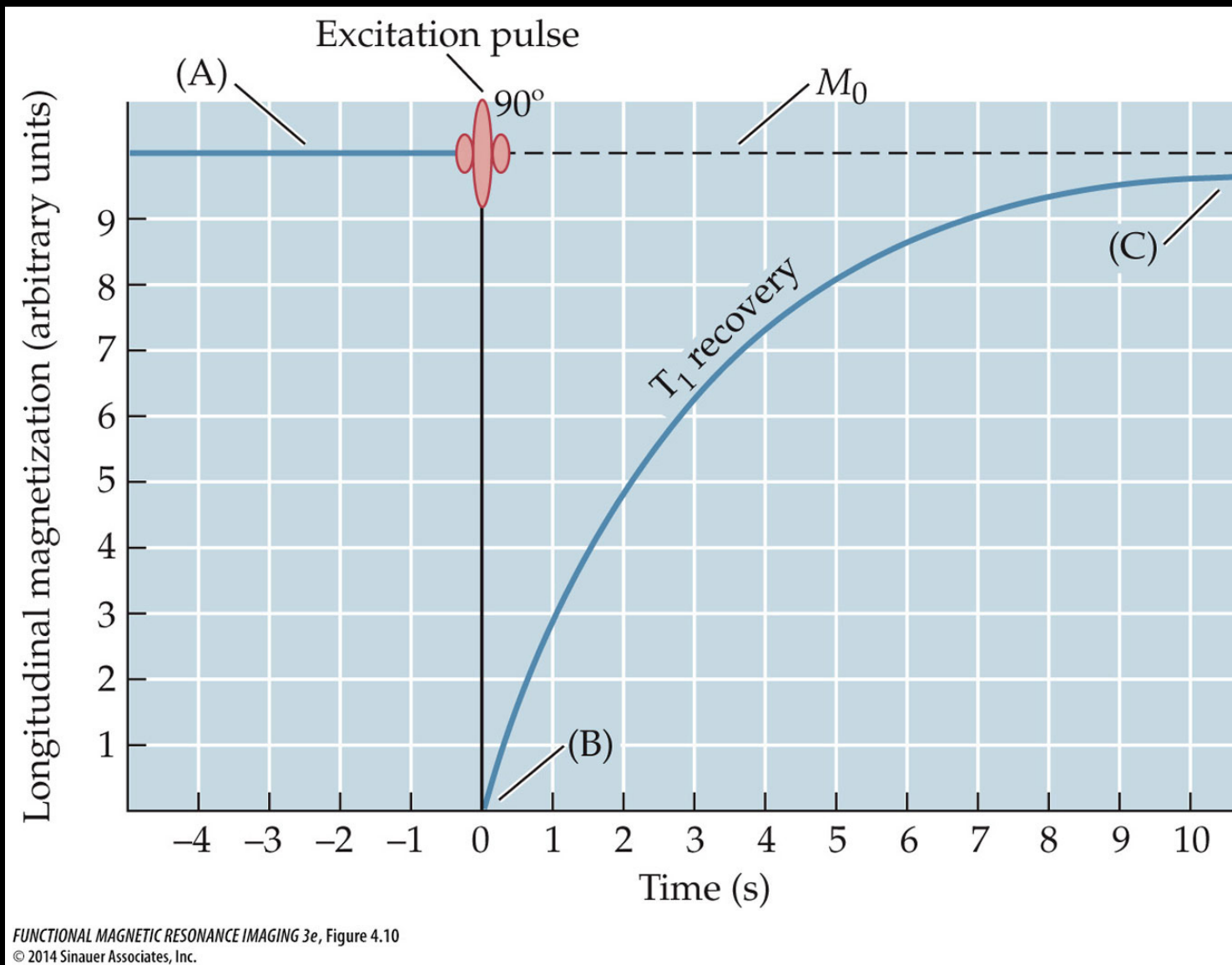
x-gradient
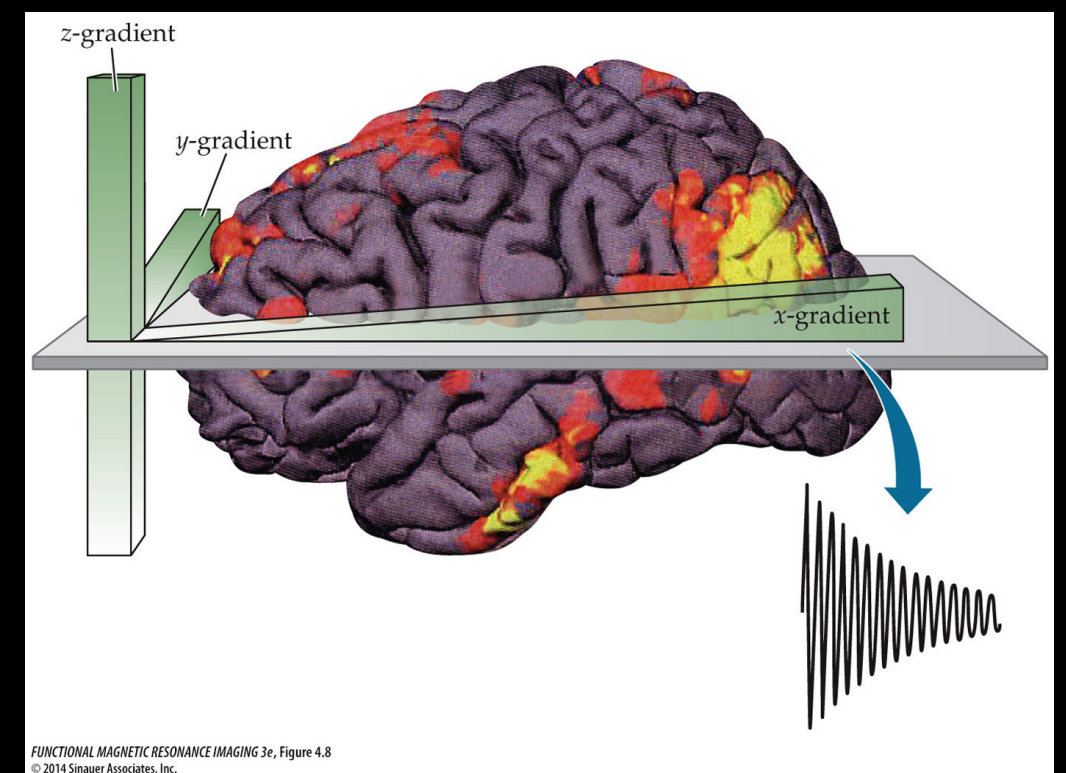
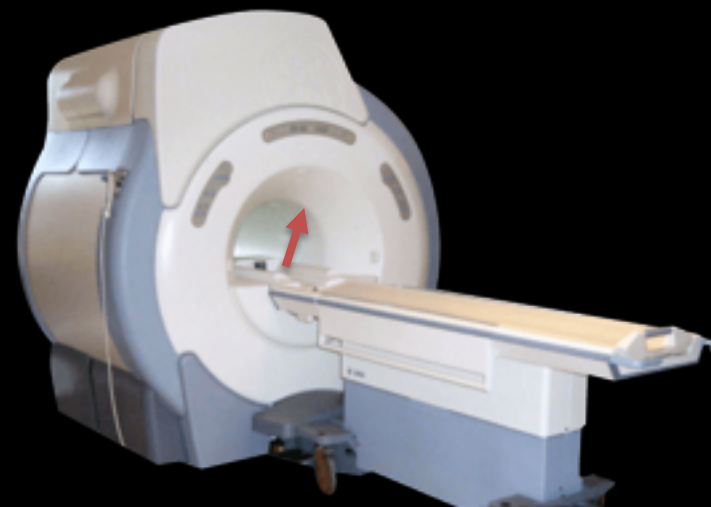# TR & TE

TR: repetition time - time between excitation (RF) pulses
TE: echo time - time between excitation pulse and data acquisition

# T1 Recovery



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 4.10
© 2014 Sinauer Associates, Inc.
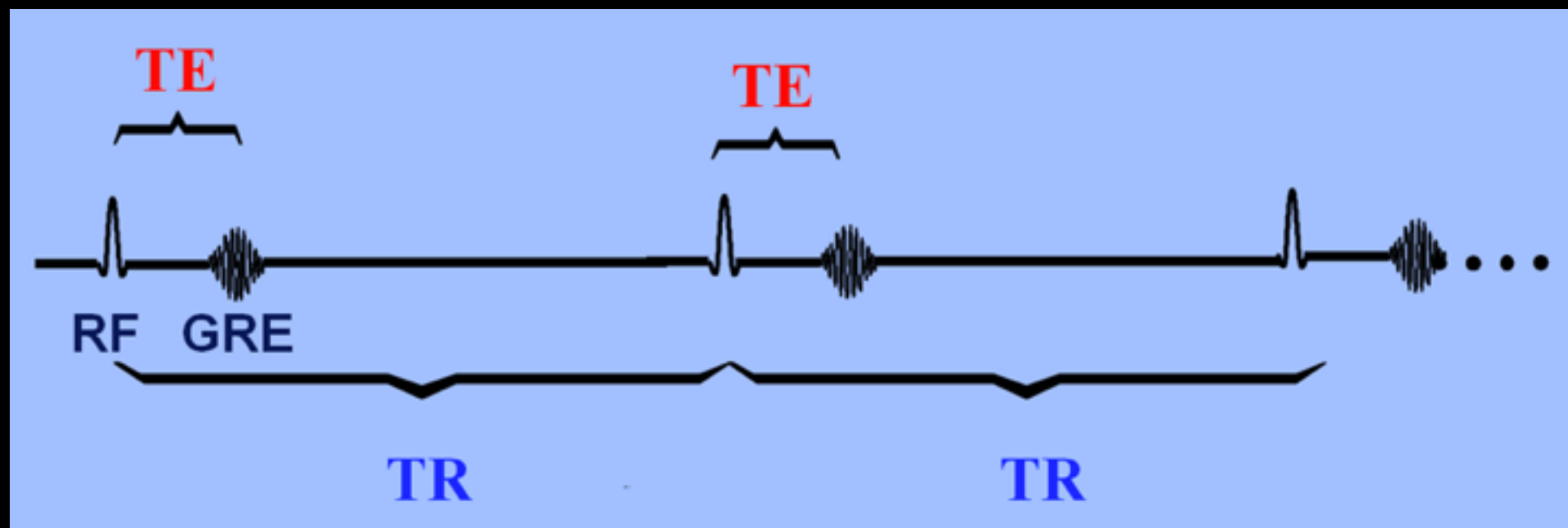
# T1 recovery and T2 Decay
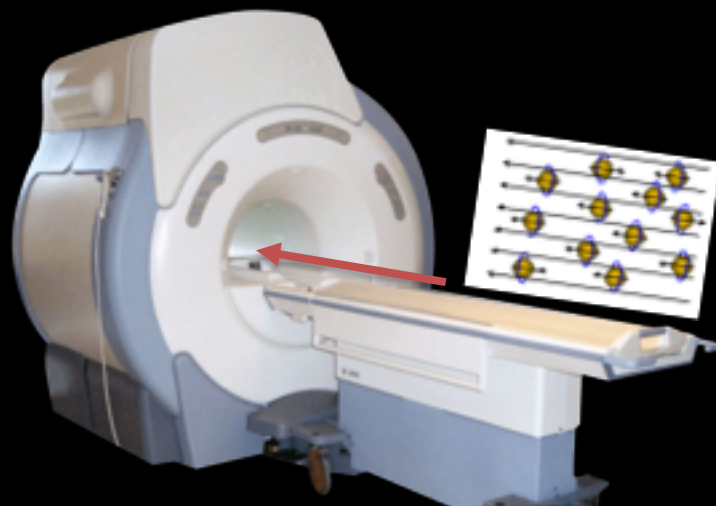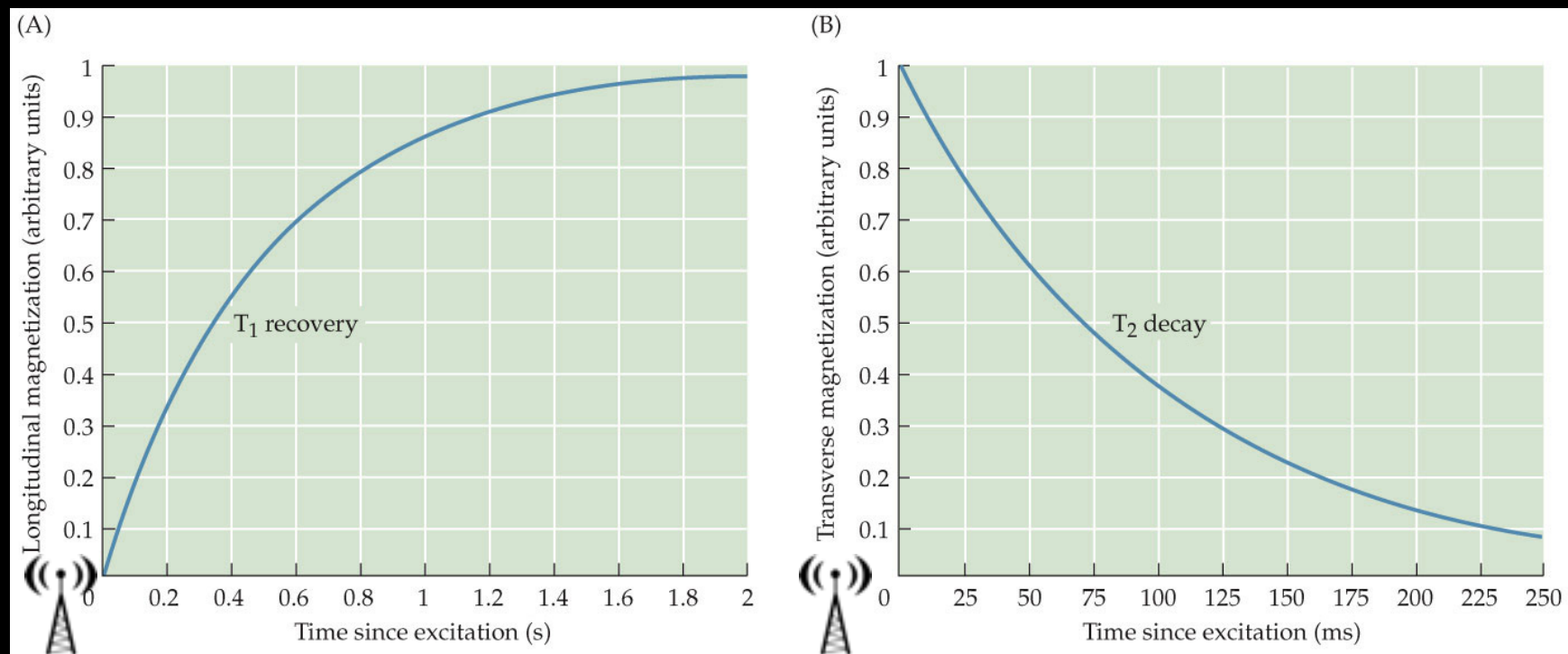
# Optimal parameters for T1 weighted



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 5.5
© 2014 Sinauer Associates, Inc.
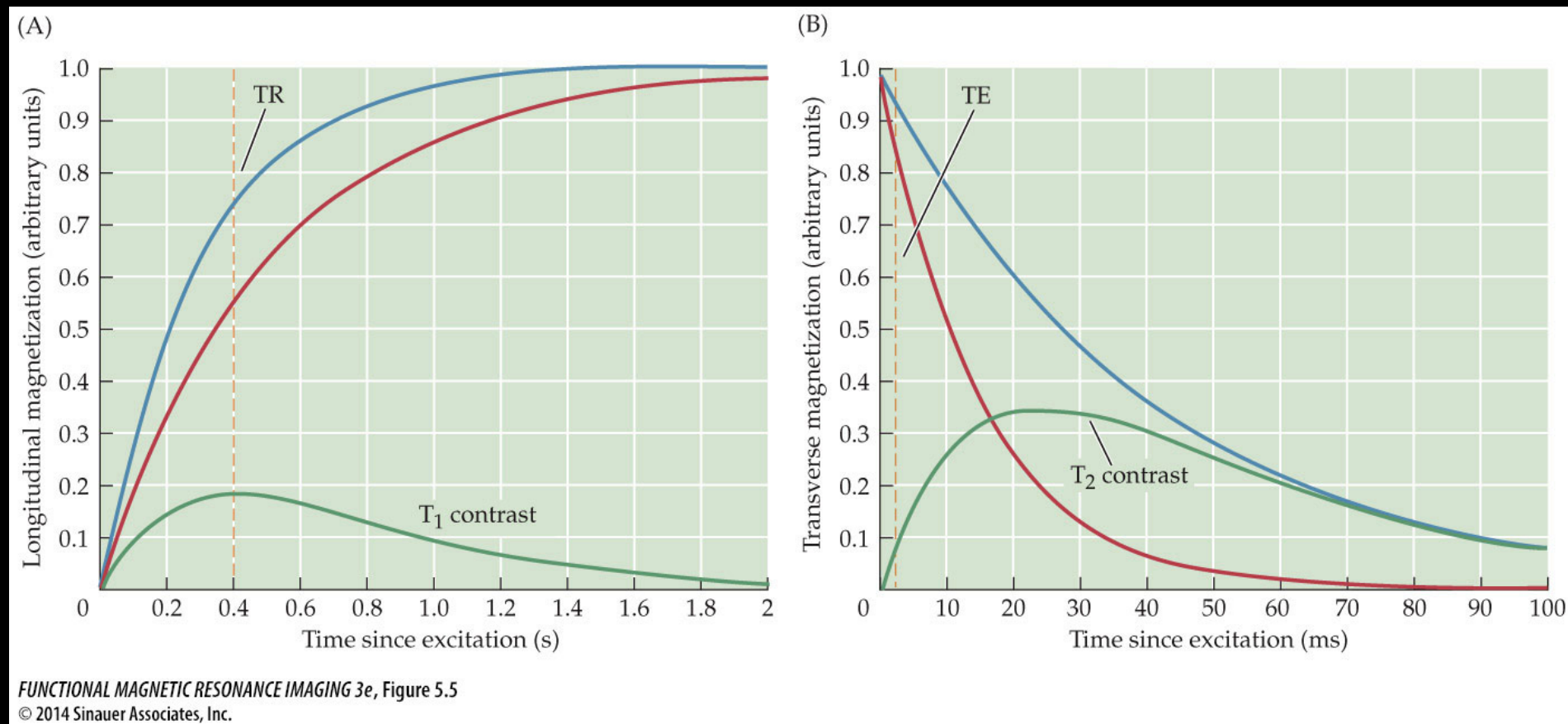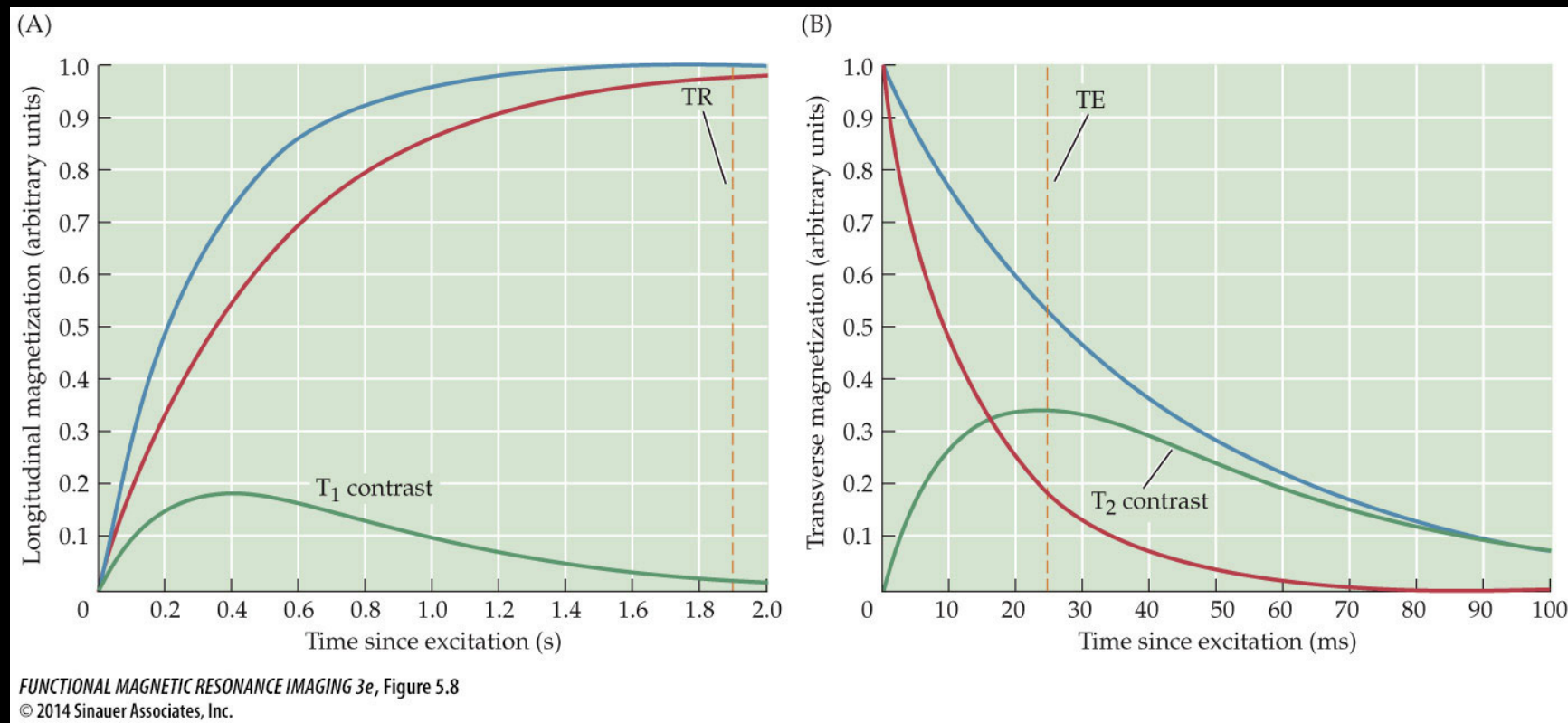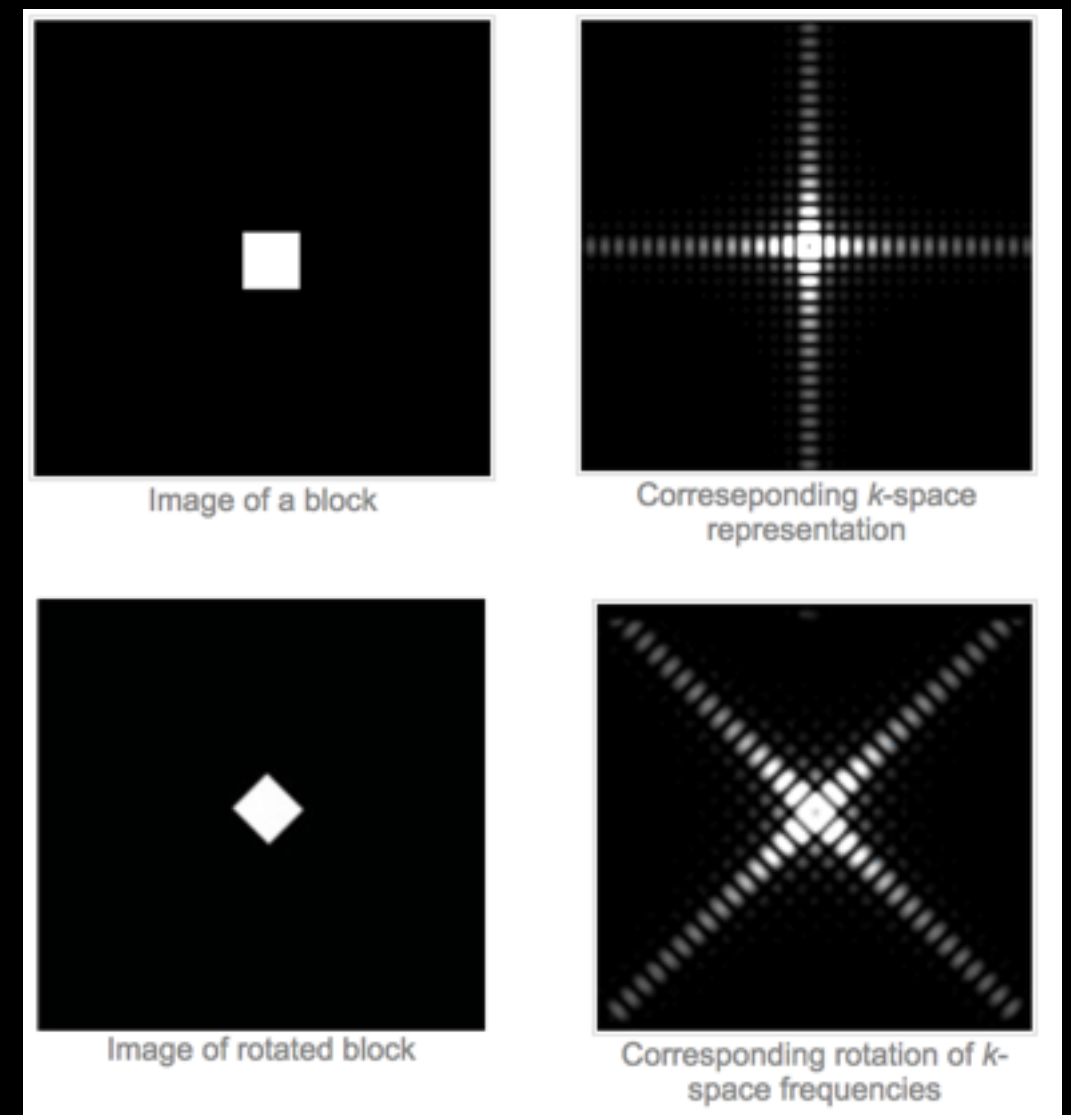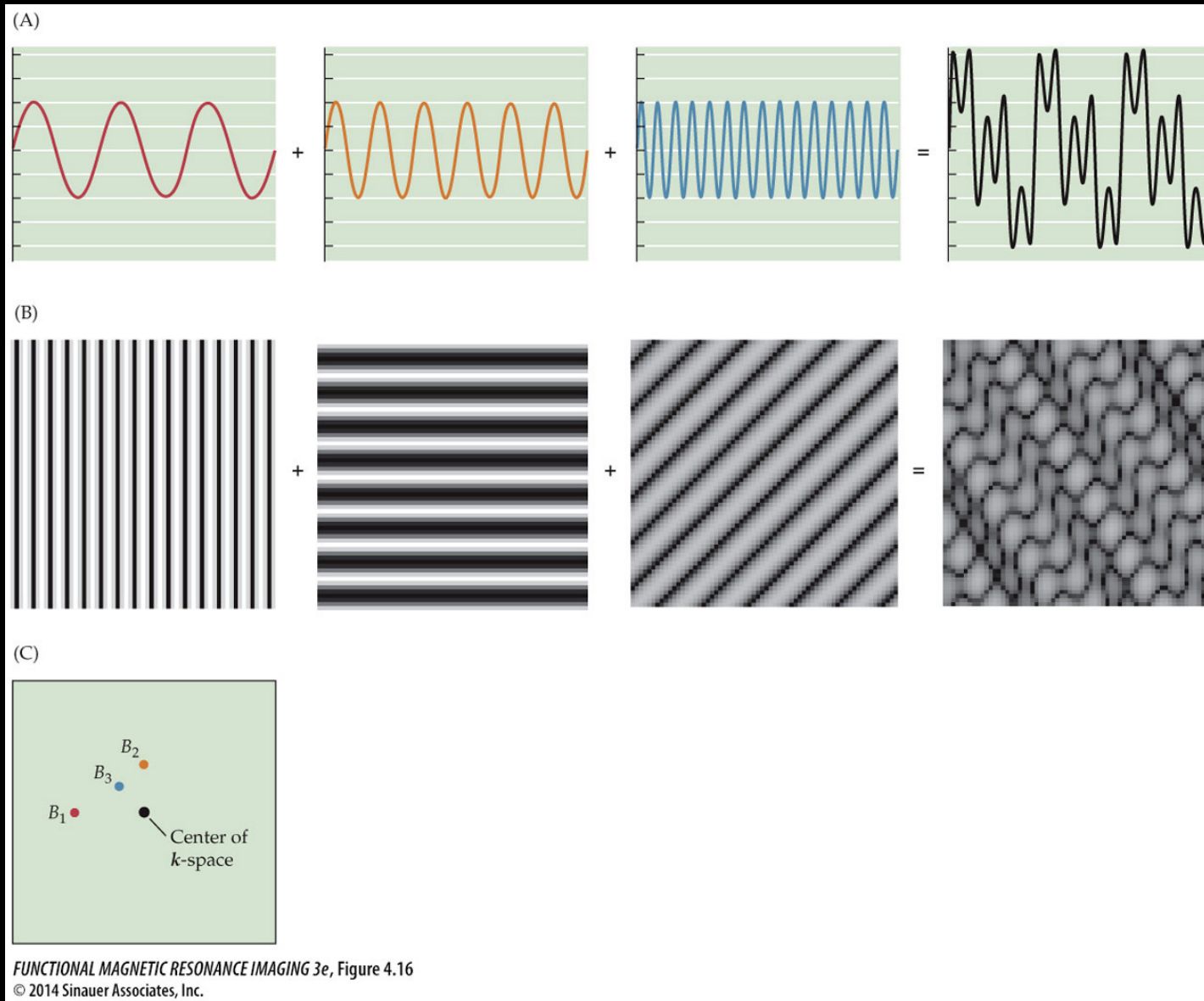
To maximize differences in tissue contrast
for T1 weighted image you need a shorter
TR and a very short TE

# Optimal parameters for T2 weighted



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 5.8
© 2014 Sinauer Associates, Inc.
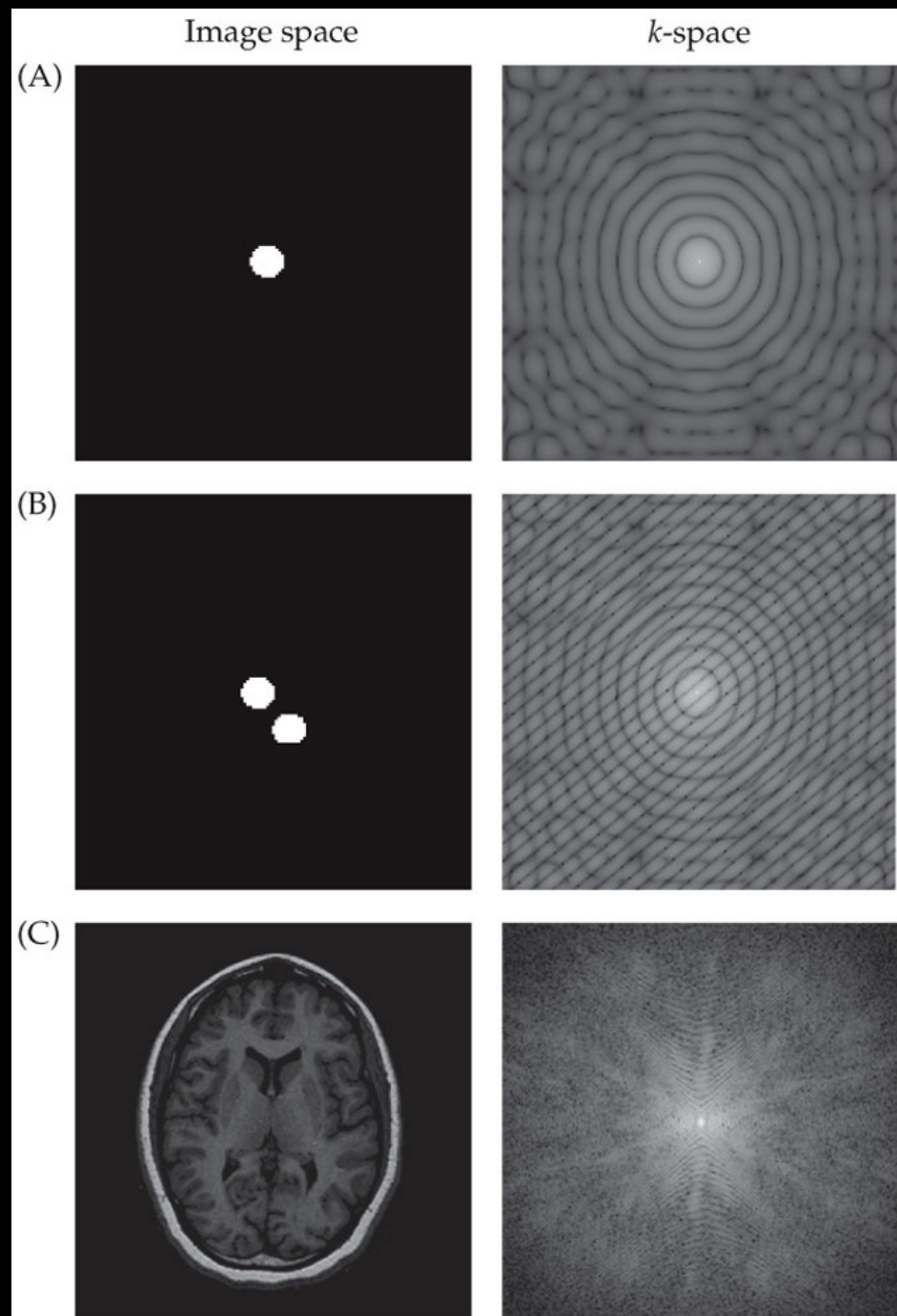
To maximize difference in tissue contrast for
T2 weighted image you need a longer TR
and shorter TE

# 2D Frequency Information converted into images



(A)

(B)

(C)

B₂
B₃
B₁
Center of k-space

FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 4.16
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Image of a block

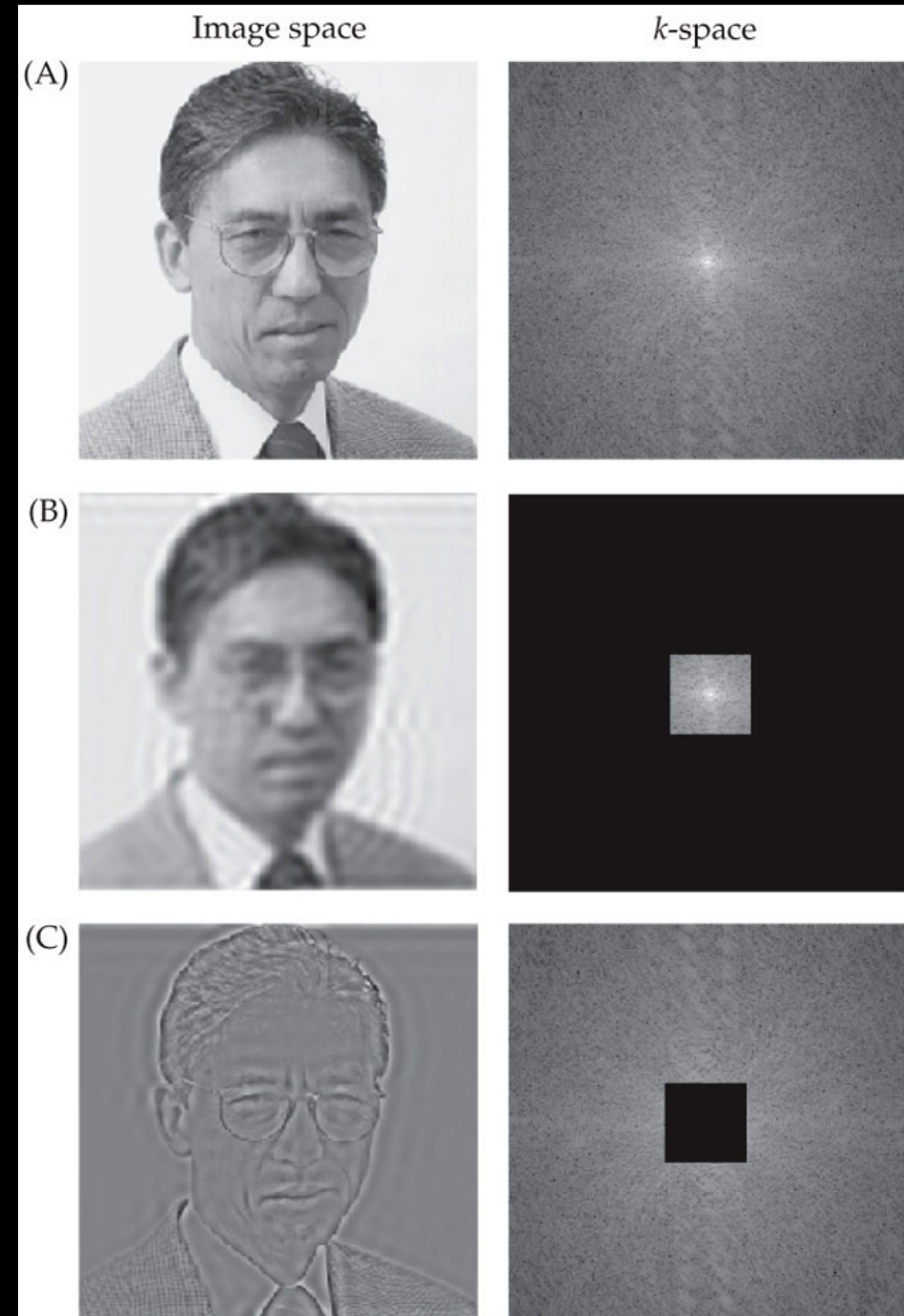Corresponding k-space representation

Image of rotated block

Corresponding rotation of k-space frequencies
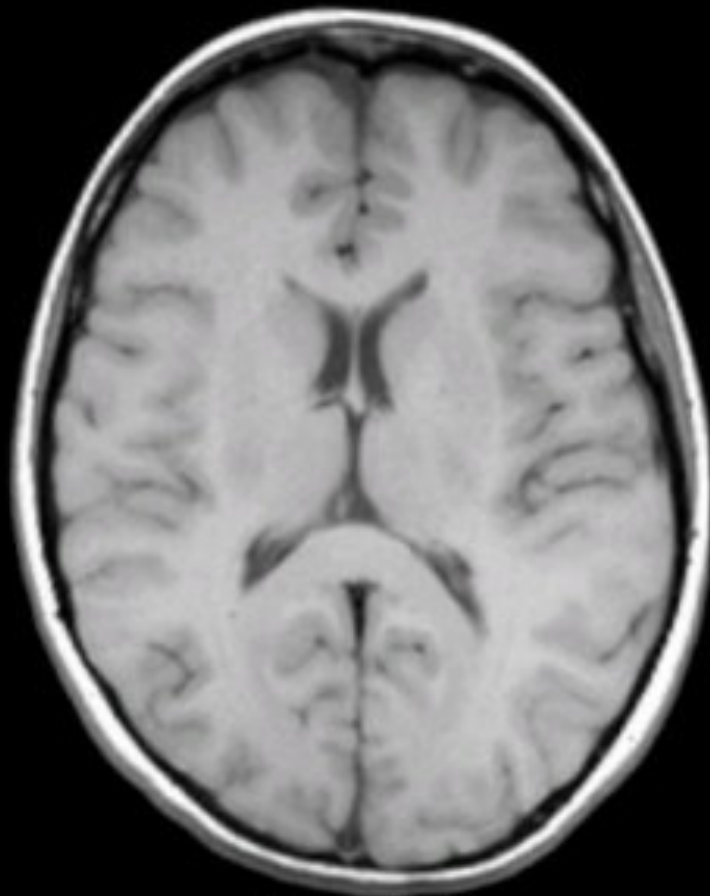
# K-space & image space



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 4.19
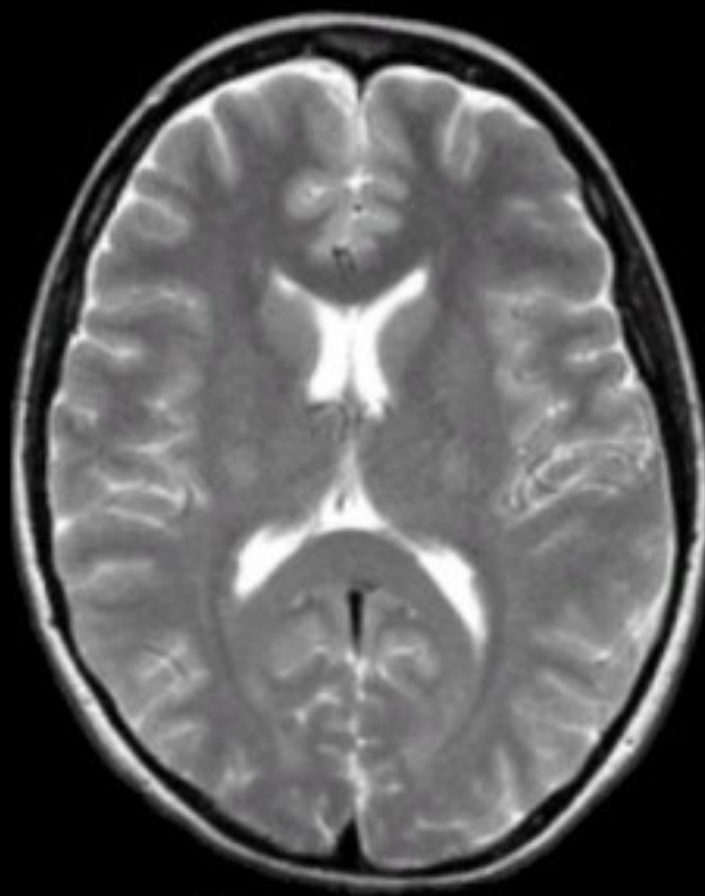© 2014 Sinauer Associates, Inc.



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 4.20
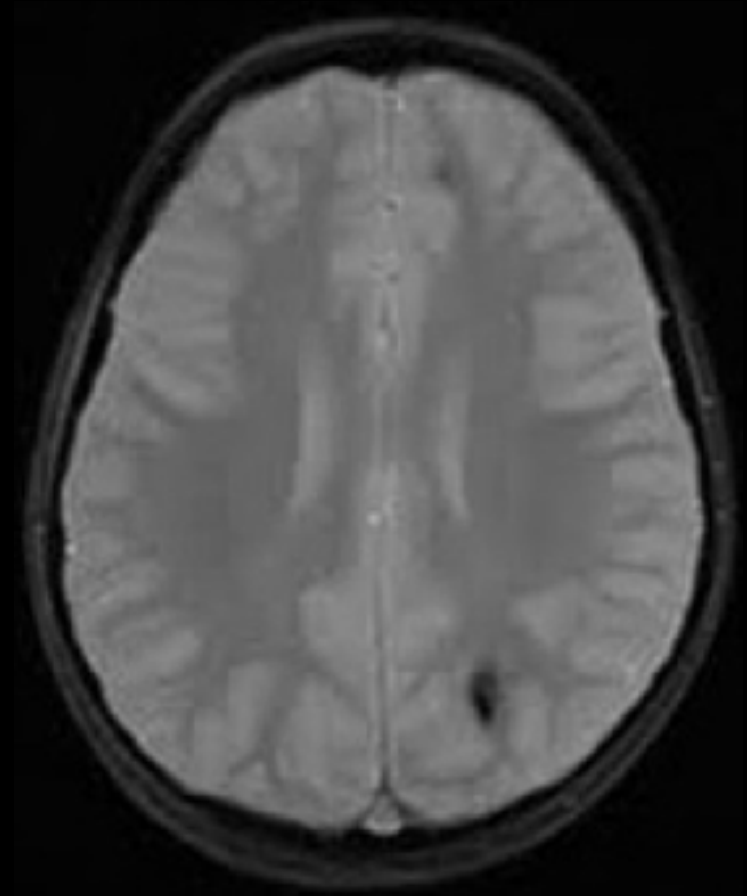© 2014 Sinauer Associates, Inc.
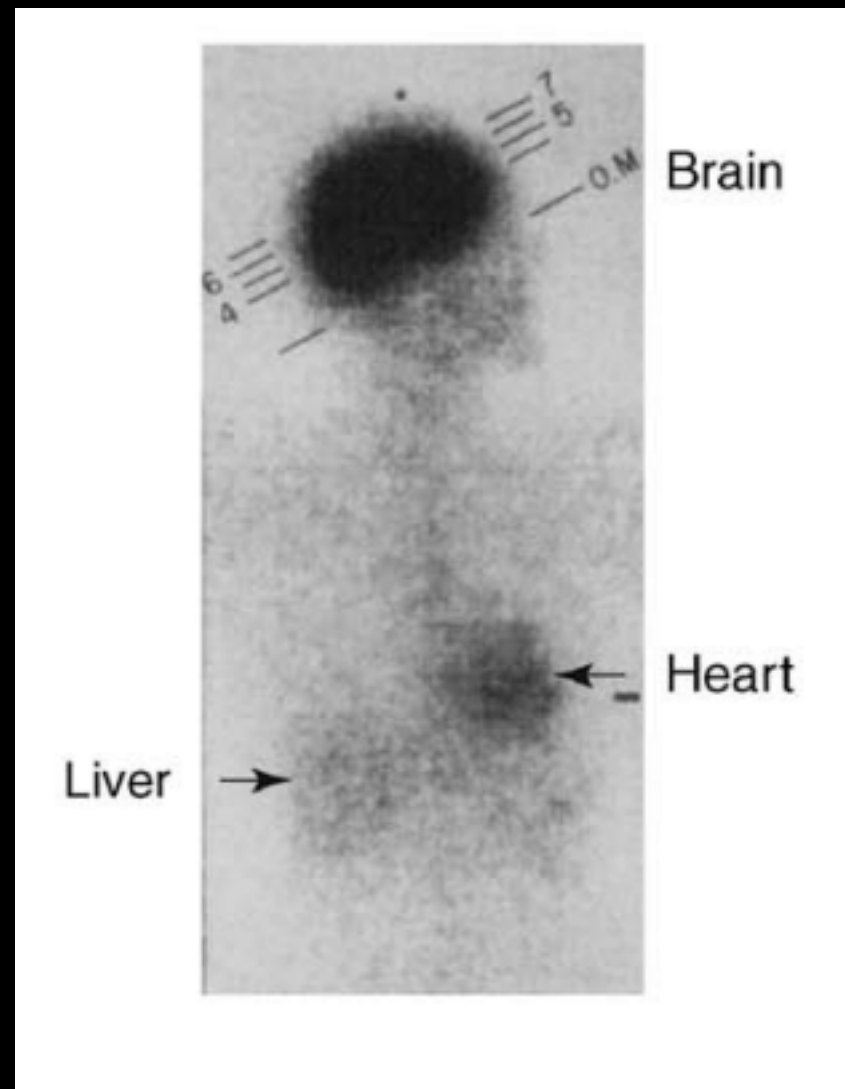
# Images



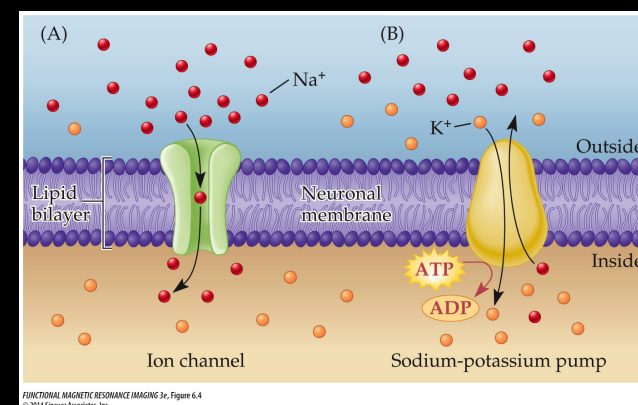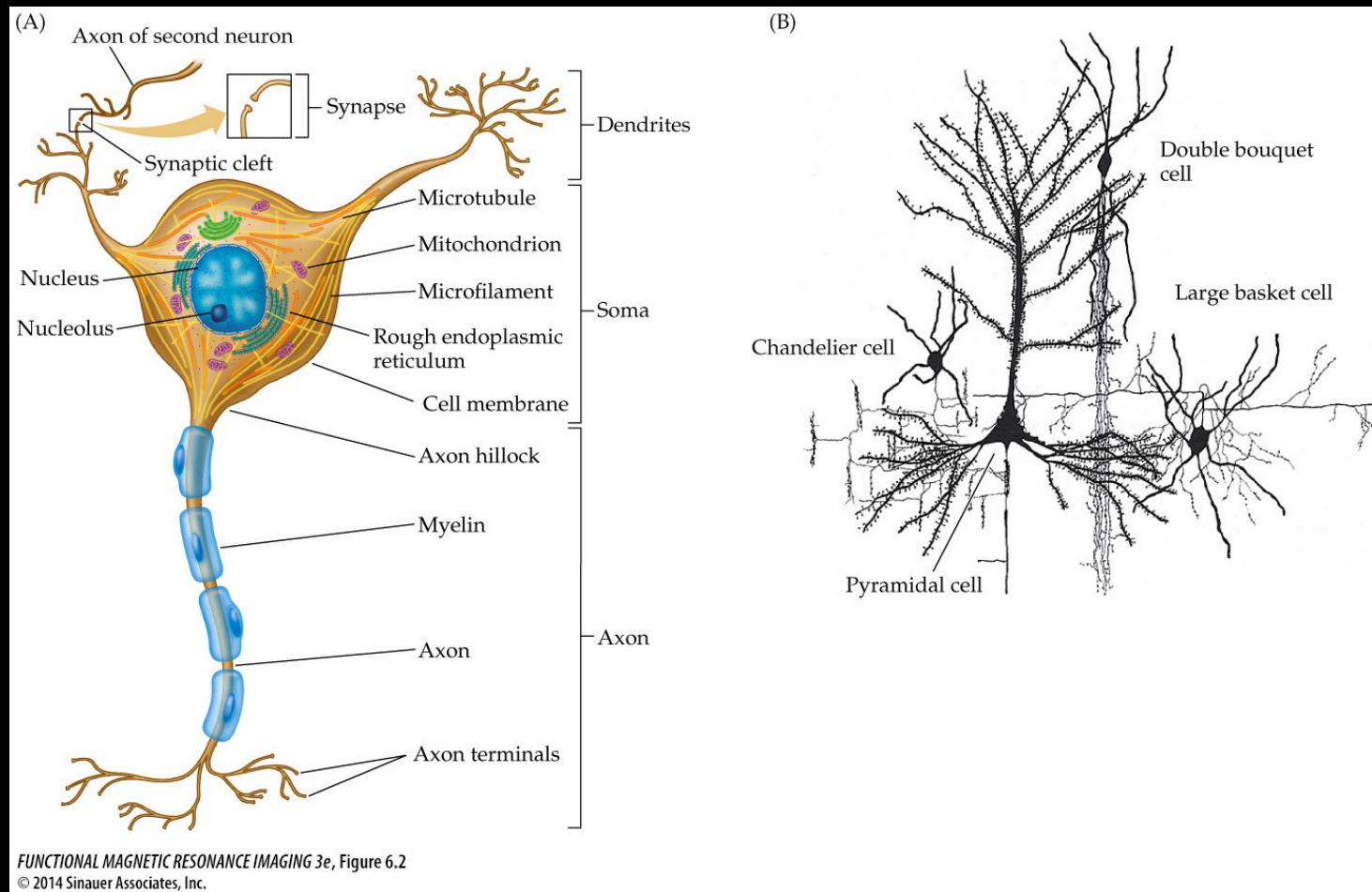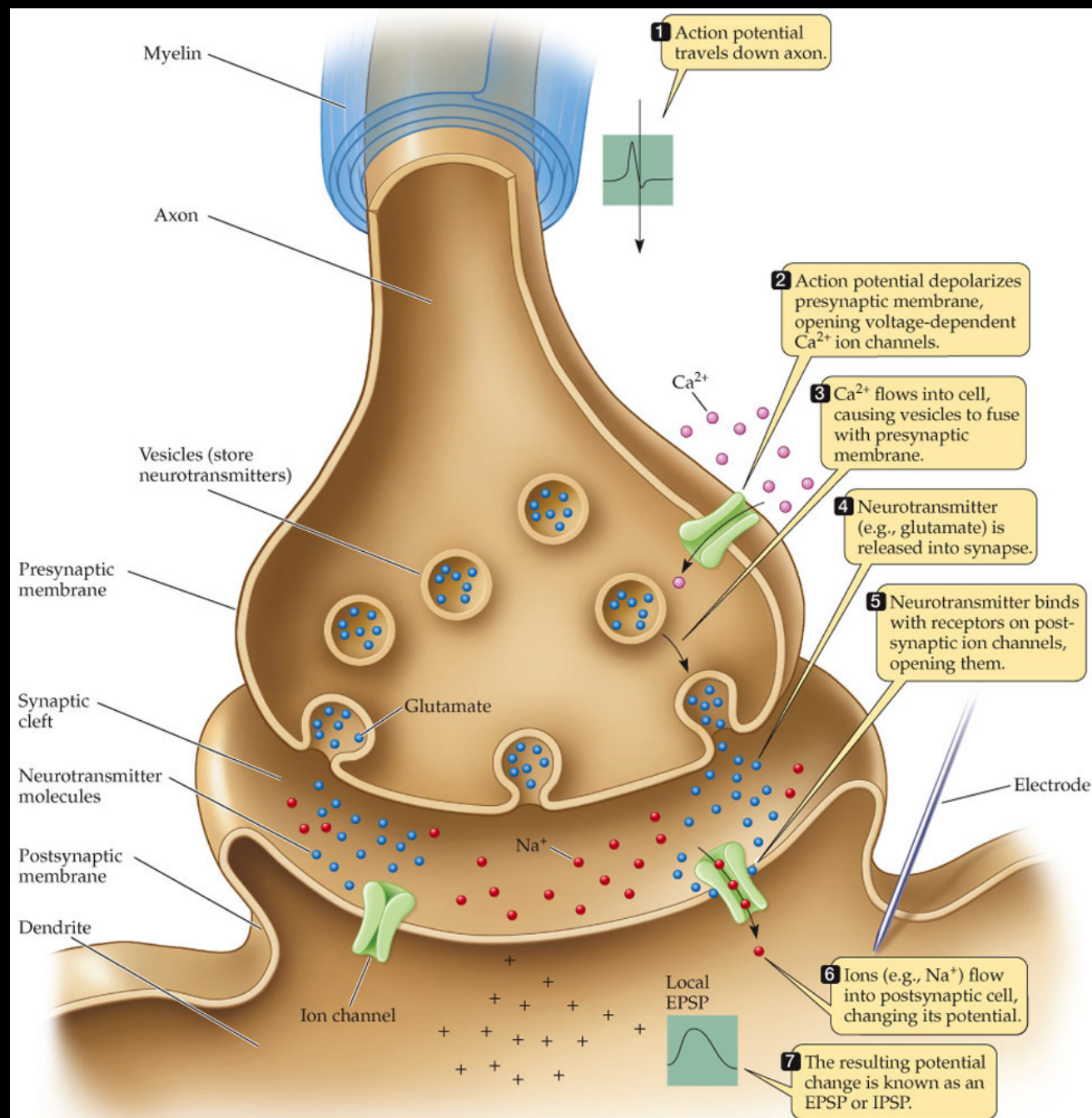T1-weighted          T2-weighted          T2*-weighted

# What is BOLD?

# The brain is active at rest



At rest the brain accounts for 11% of cardiac output
20% of energy consumption

Alavi and Reivich, 2002, Raichle, 2010

(A)

Axon of second neuron

Synapse

Synaptic cleft

Dendrites

Microtubule

Mitochondrion

Nucleus

Microfilament

Nucleolus

Rough endoplasmic reticulum

Soma

Cell membrane

Axon hillock

Myelin

Axon

Axon

Axon terminals

(B)

Double bouquet cell

Large basket cell

Chandelier cell

Pyramidal cell

(A)

Na+

(B)

K+

Outside

Lipid bilayer

Neuronal membrane

ATP

ADP

Inside

Ion channel

Sodium-potassium pump

FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 6.5
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# Rodent brain energy budget



Postsynaptic potentials
Action potentials
Resting potentials
Presynaptic transmitter release
Transmitter recycling
Housekeeping

25%
37.5%
3%
3.8%
15%
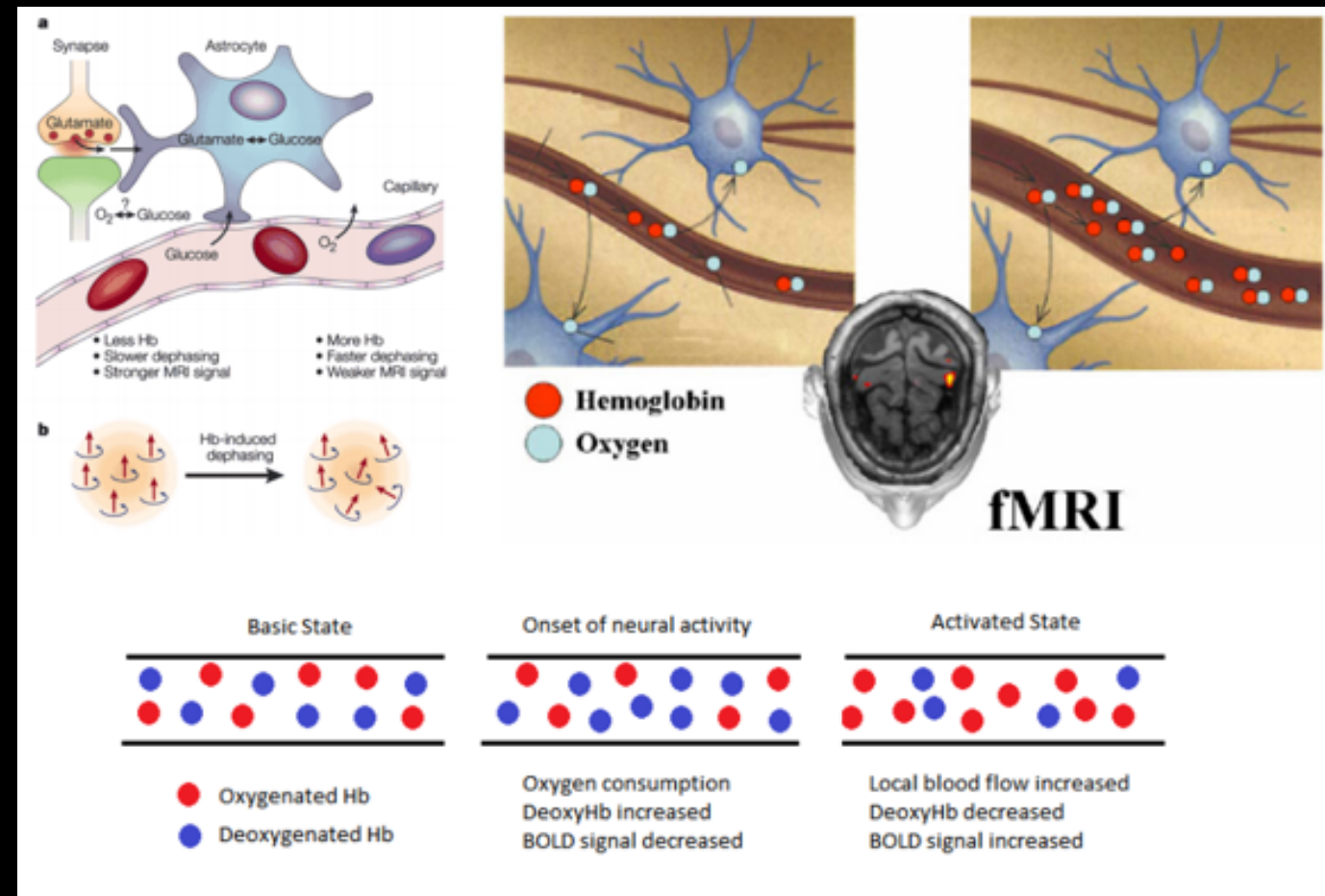15.8%

FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 6.8
© 2014 Sinauer Associates, Inc.
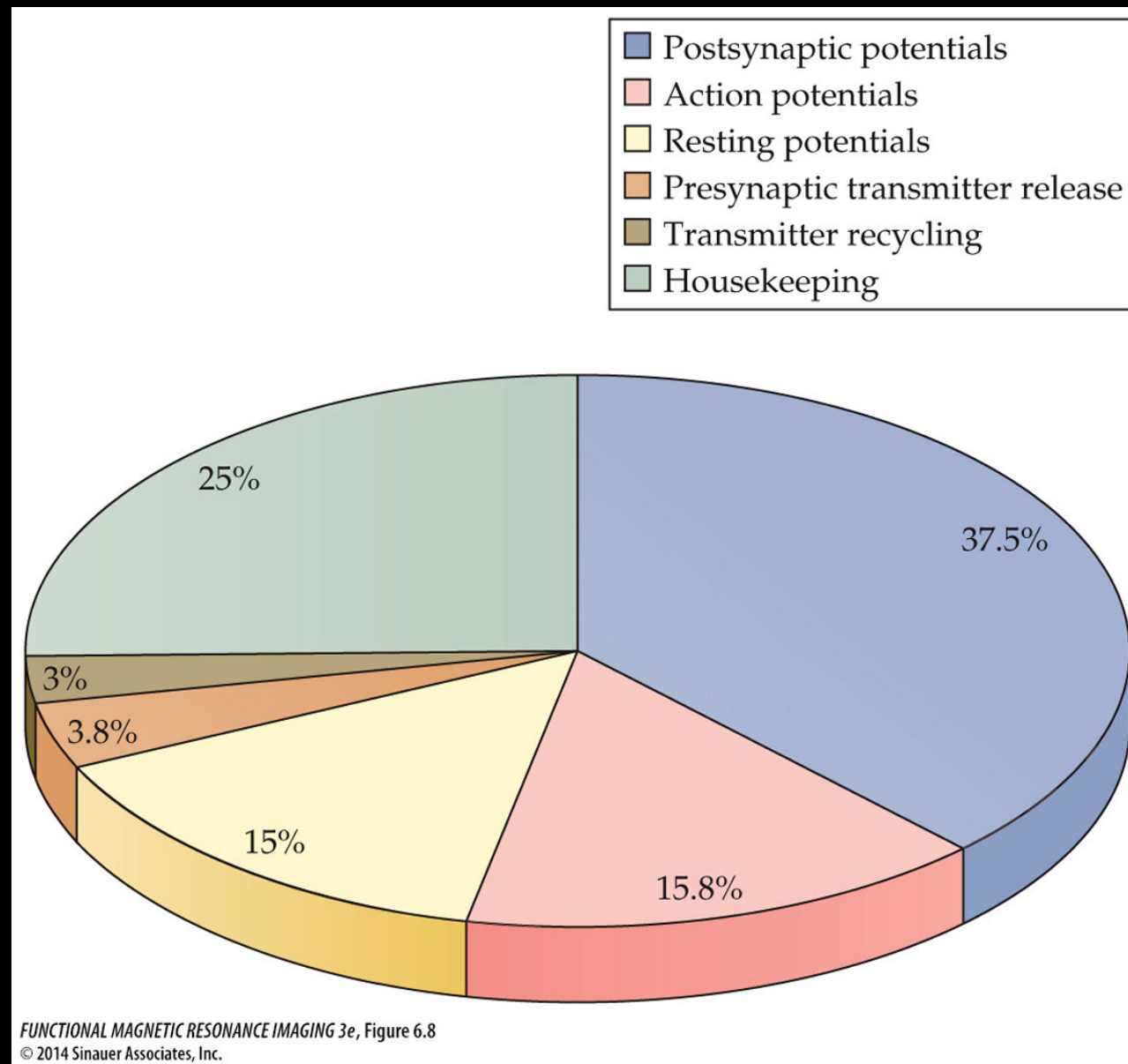
# Blood Oxygenated Level Dependent (BOLD) signal
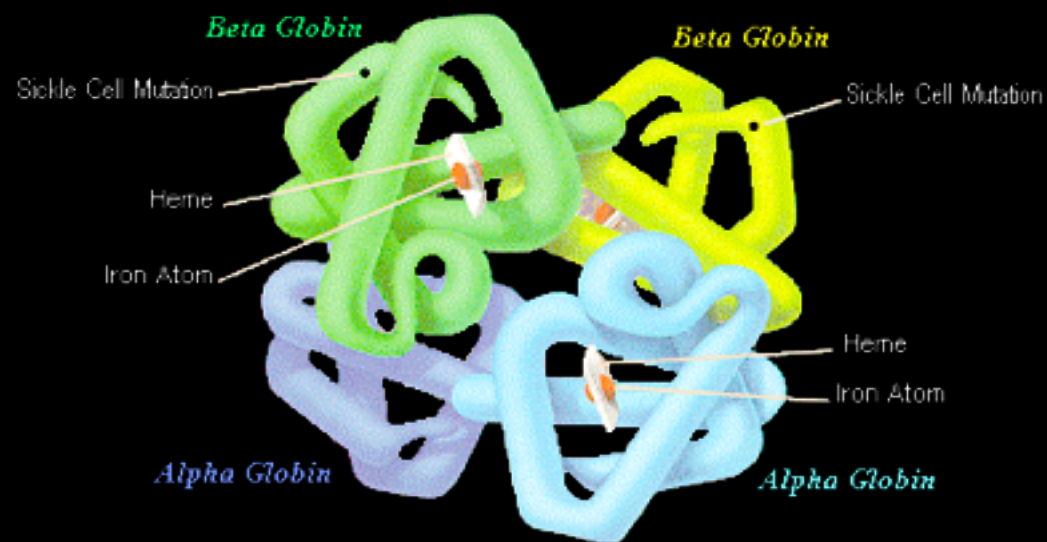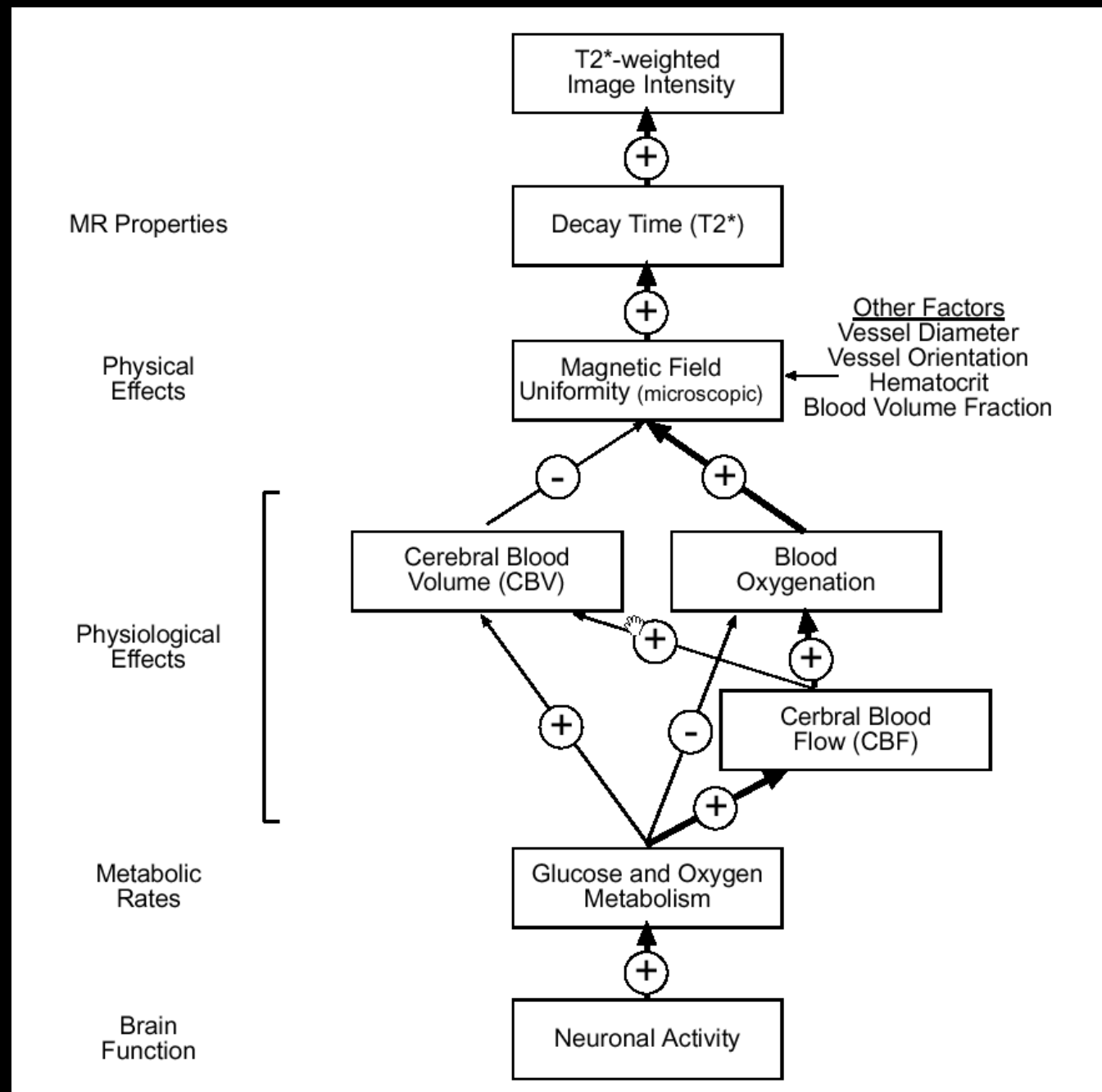

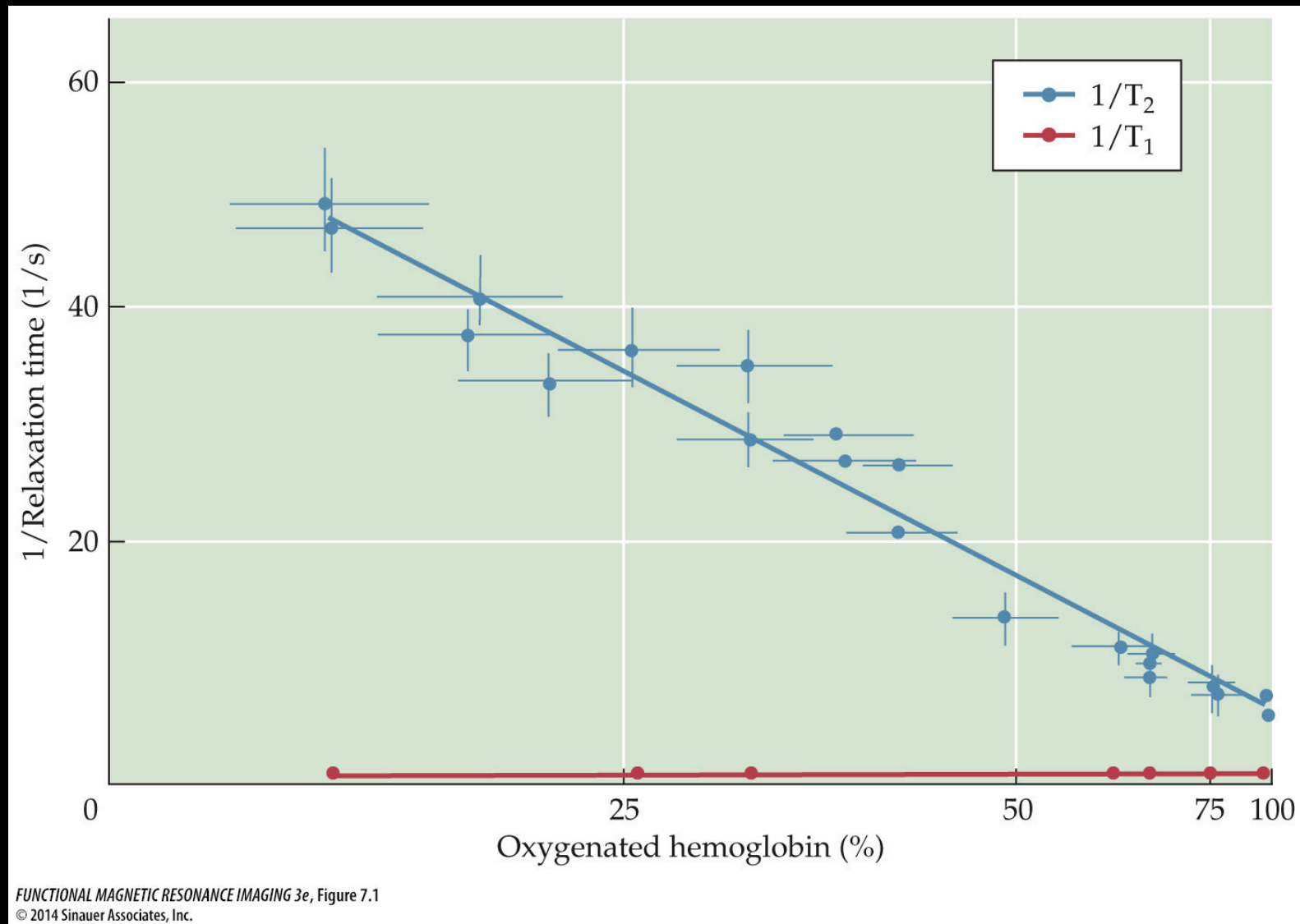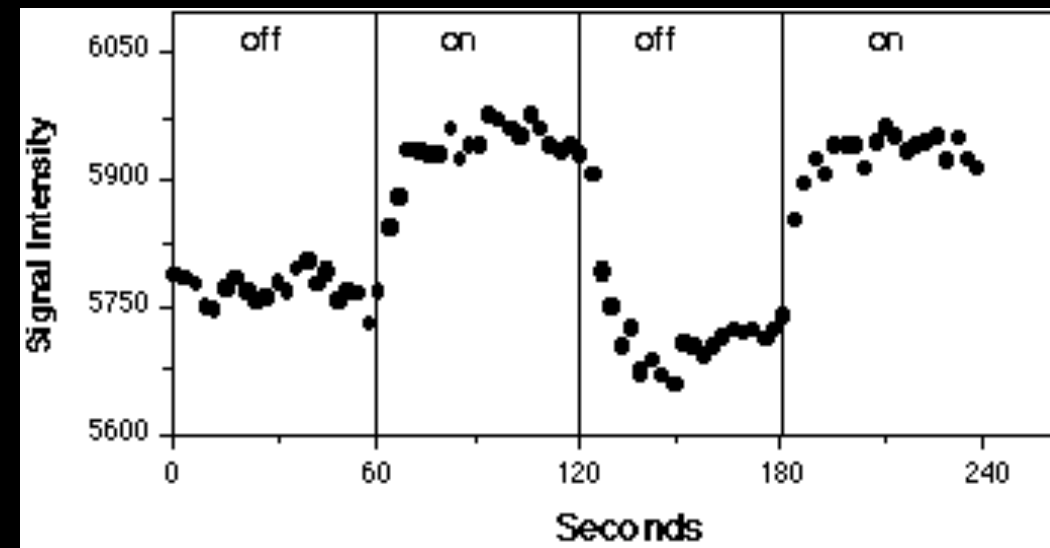
Oxygenated hemoglobin is diamagnetic
Deoxygenated hemoglobin is paramagnetic

# BOLD Signal
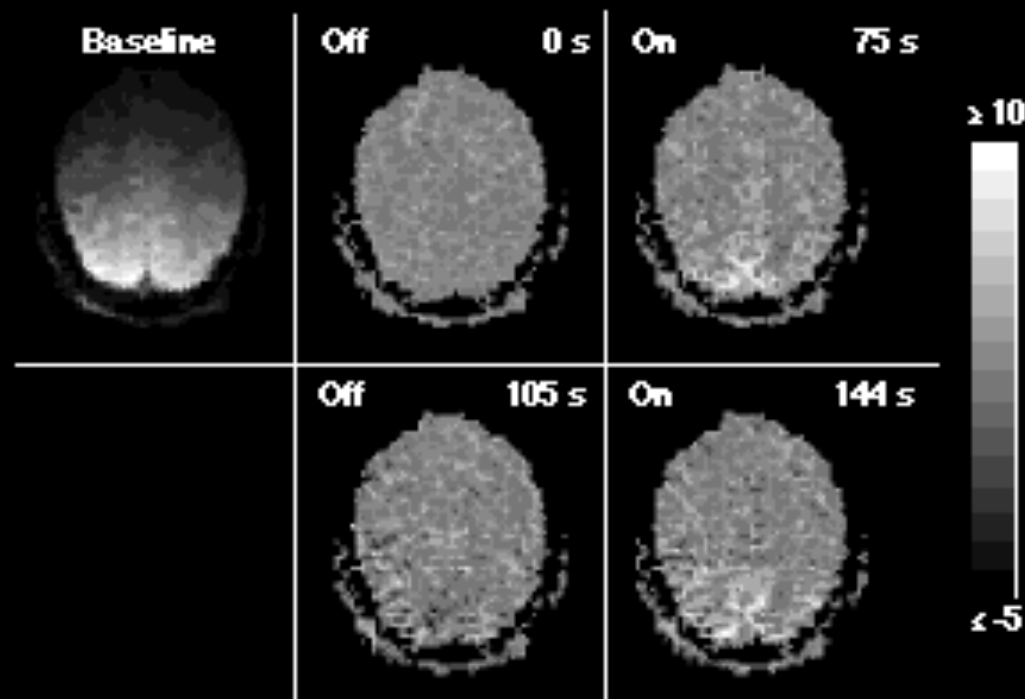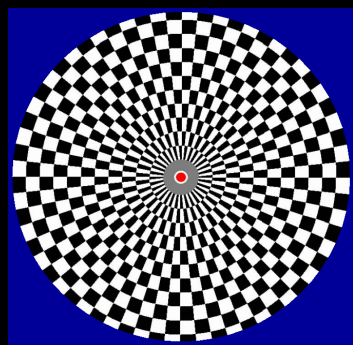
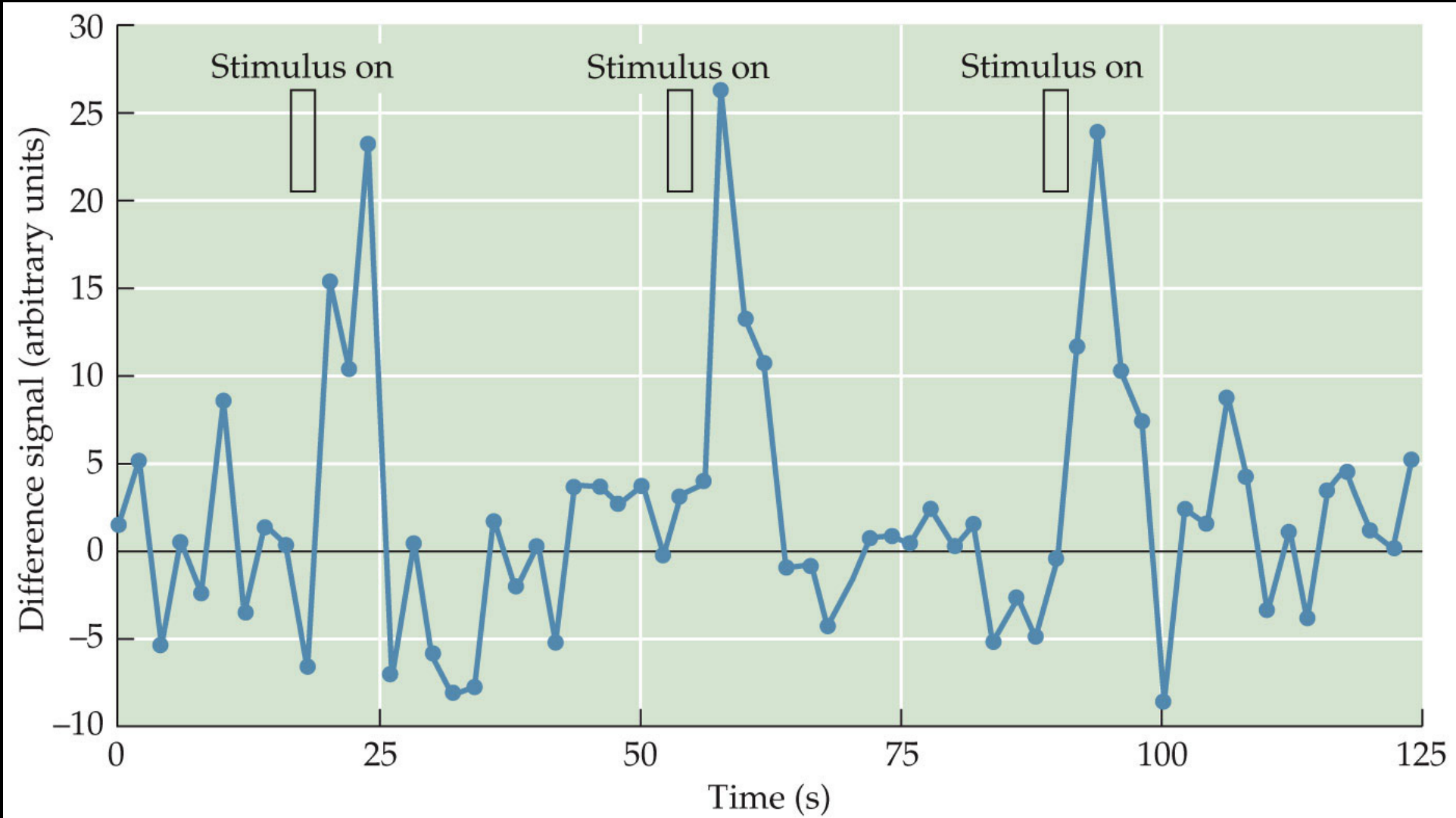# Blood oxygenation and T1/T2



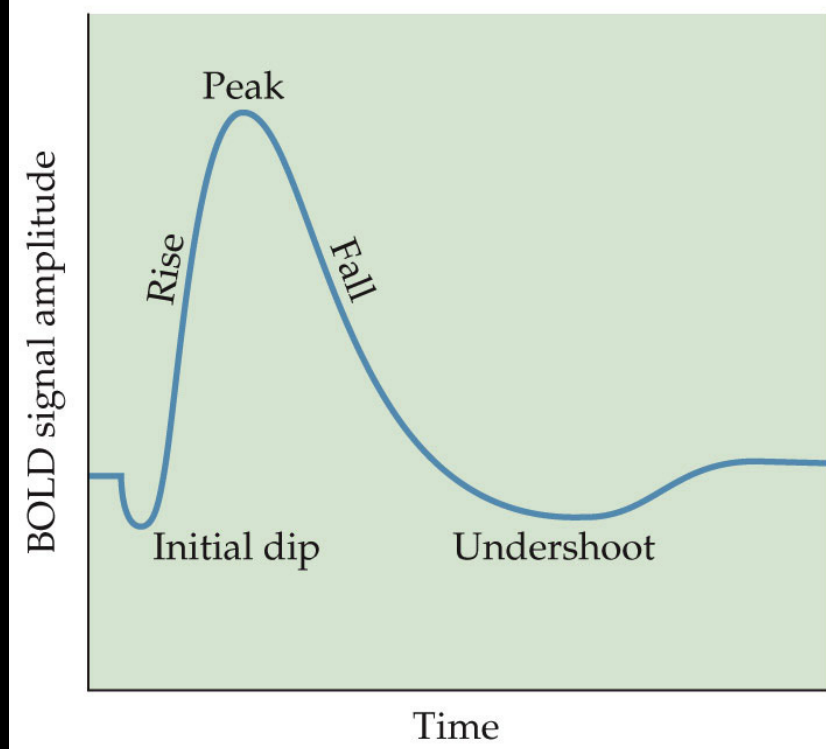FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.1
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# Stimulus presentation changes BOLD in visual cortex



Kwong et al., 1992

FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.9
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(A)

BOLD signal amplitude

Peak

Rise

Fall

Initial dip          Undershoot

Time

(B)

Plateau

Rise

Fall

Initial dip          Undershoot

Time

FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.10
© 2014 Sinauer Associates, Inc.
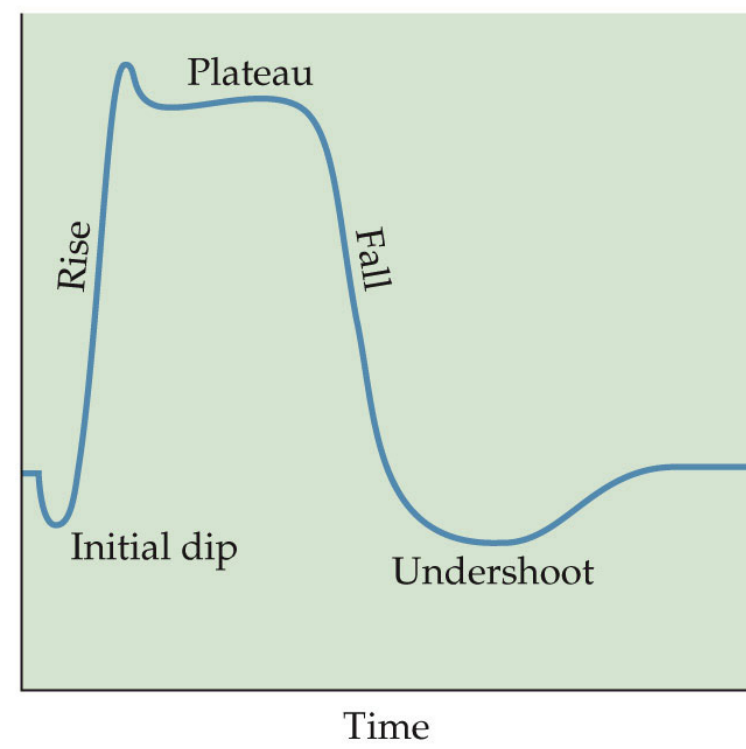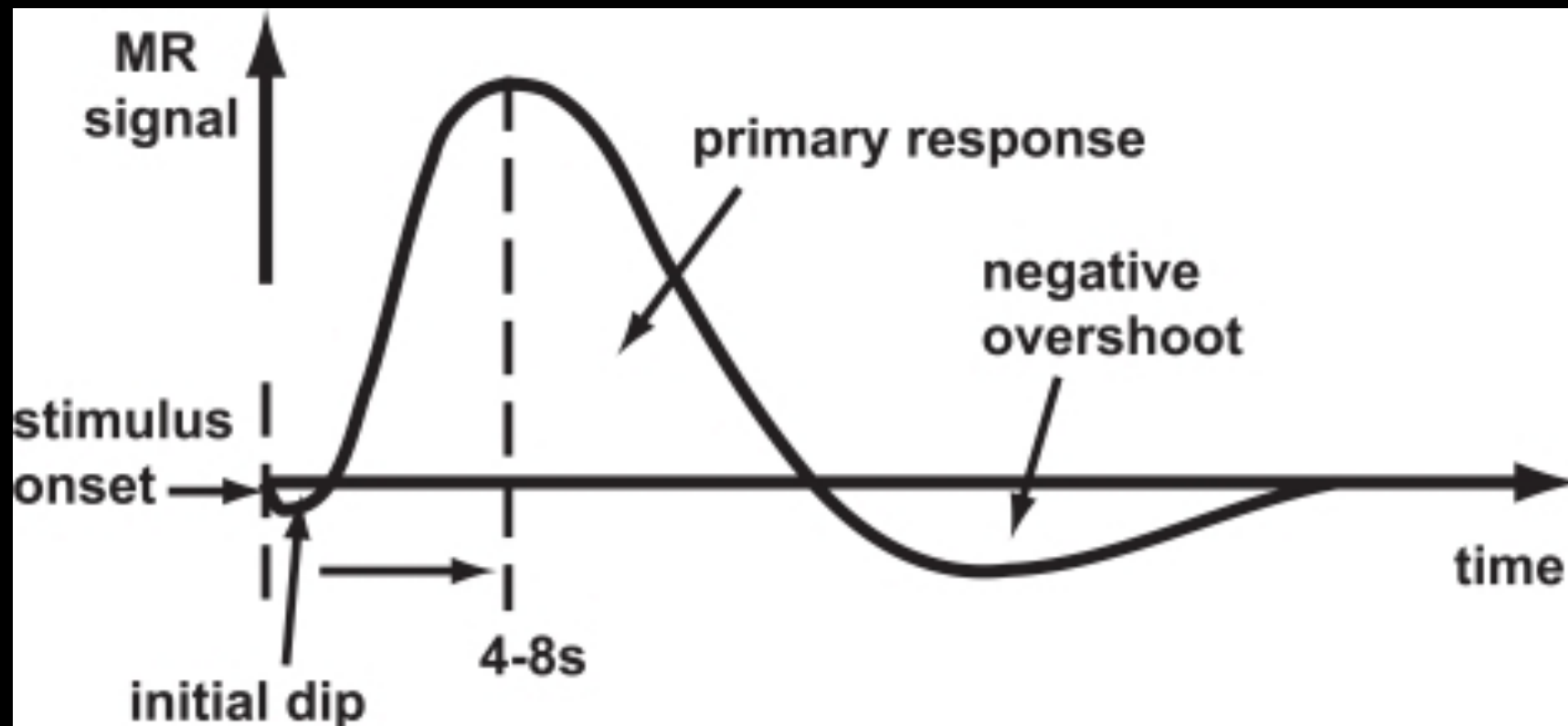
# Hemodynamic Response Function (HRF)

# Sampling resolution



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.20
© 2014 Sinauer Associates, Inc.
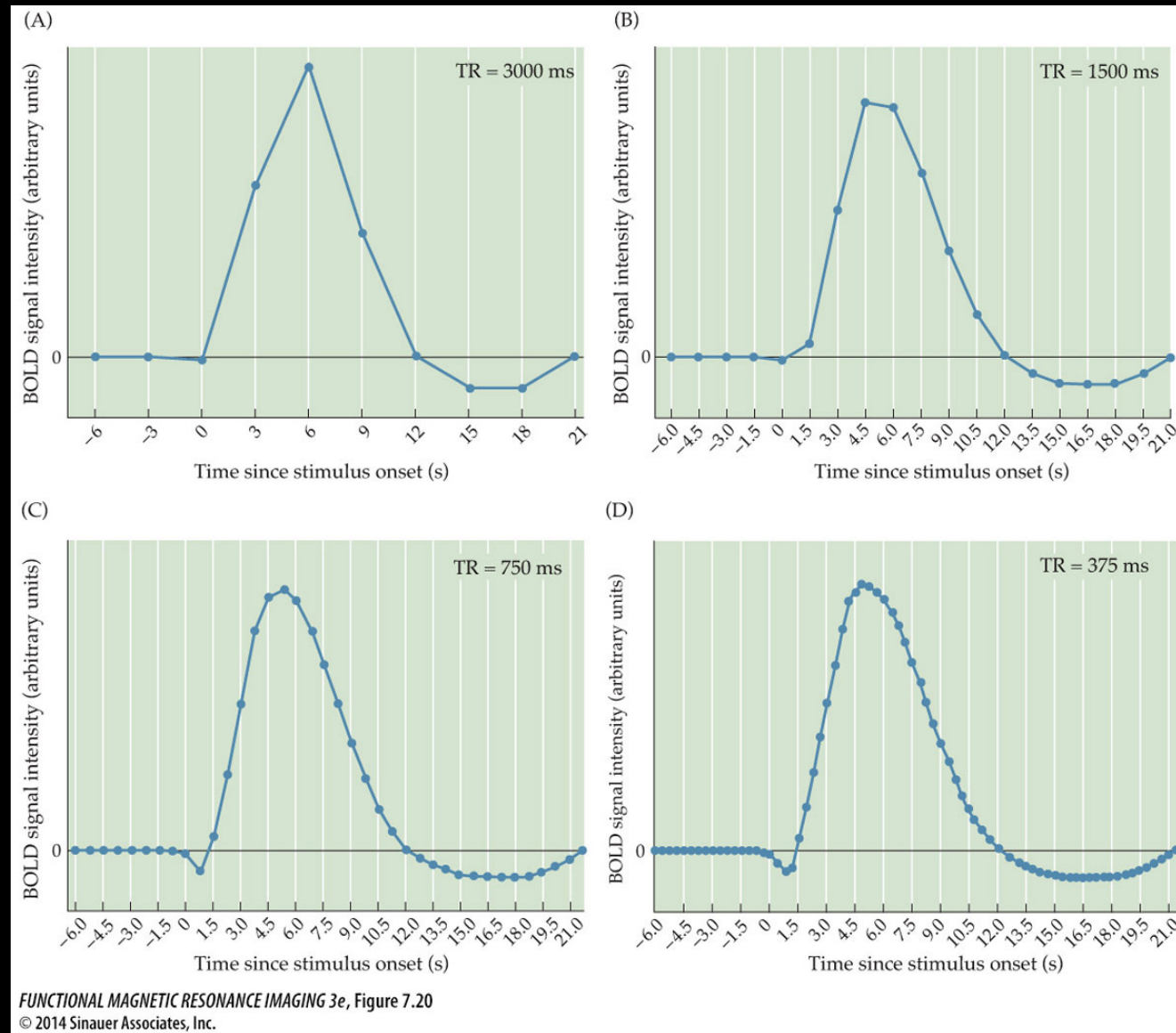
# Assume HRF is Linear and Time Invariant



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.26
© 2014 Sinauer Associates, Inc.

# Scaling & Superposition



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.28
© 2014 Sinauer Associates, Inc.
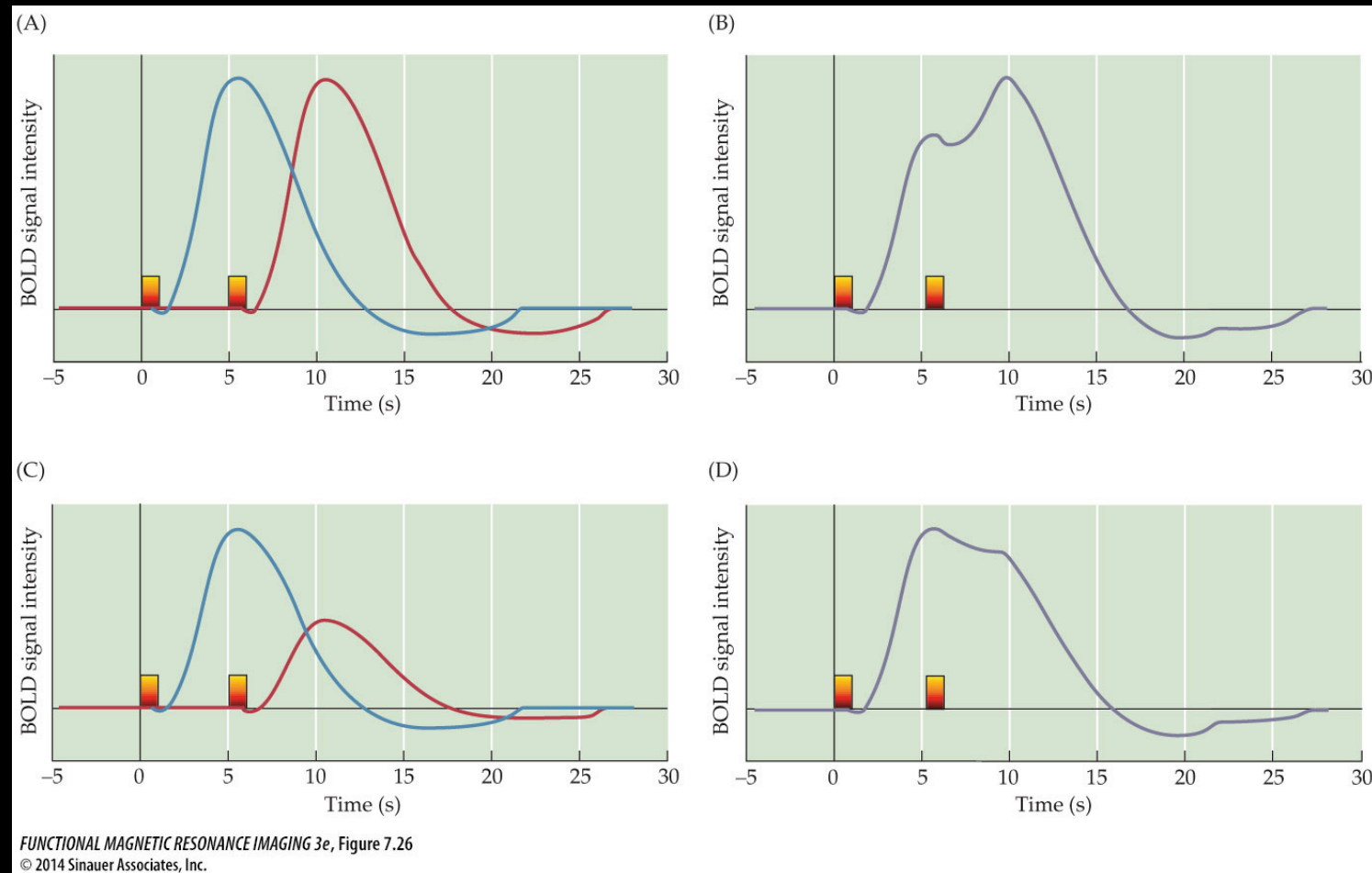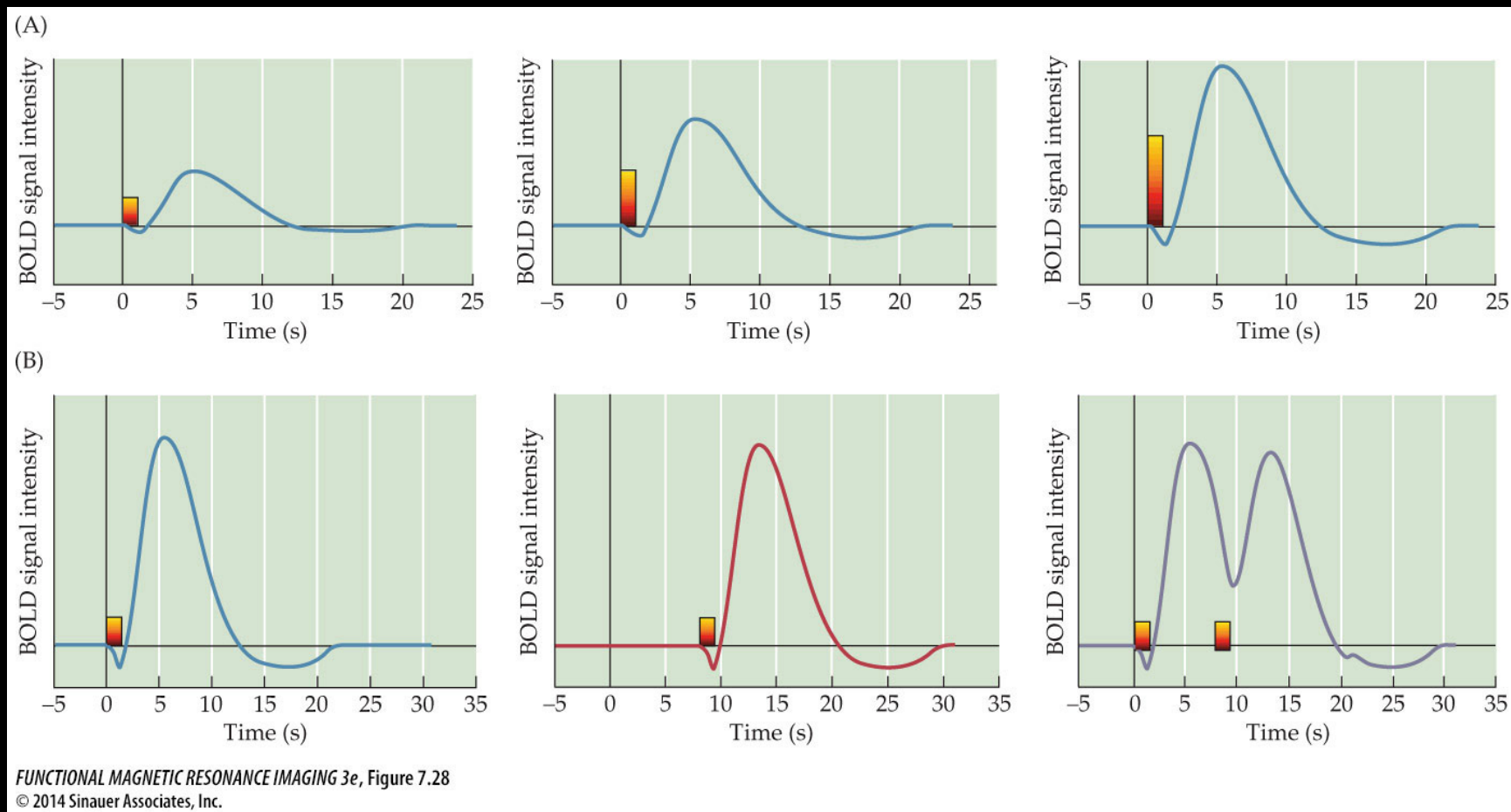
# Do BOLD responses summate linearly?



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.29
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# HRF Nonlinearities



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.30
© 2014 Sinauer Associates, Inc.
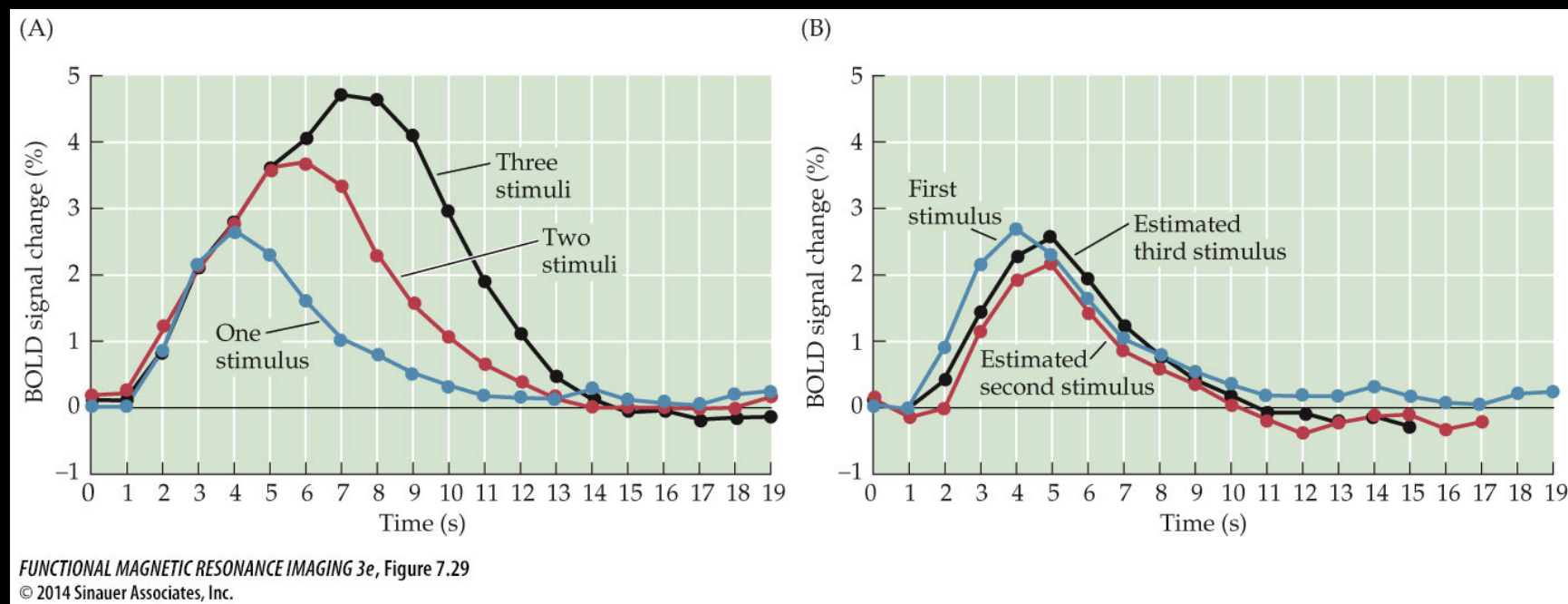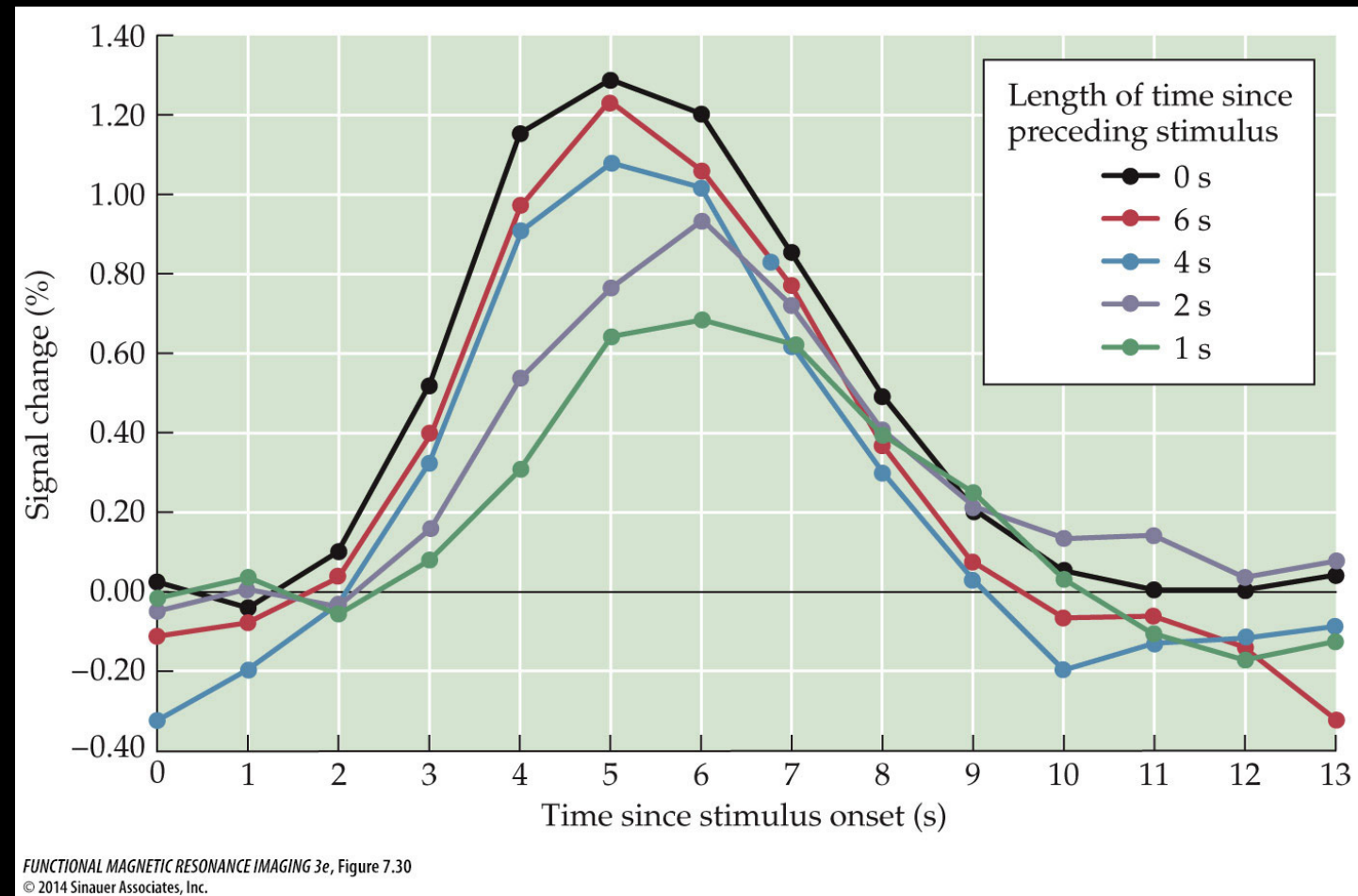
# What exactly is BOLD Measuring?

# BOLD Correlates



FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.11
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FUNCTIONAL MAGNETIC RESONANCE IMAGING 3e, Figure 7.15
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# Negative BOLD signals



Shmuel et al. 2006, *Nat. Neurosci.*

# Single unit vs fMRI



Mukamel et al., 2005 Science
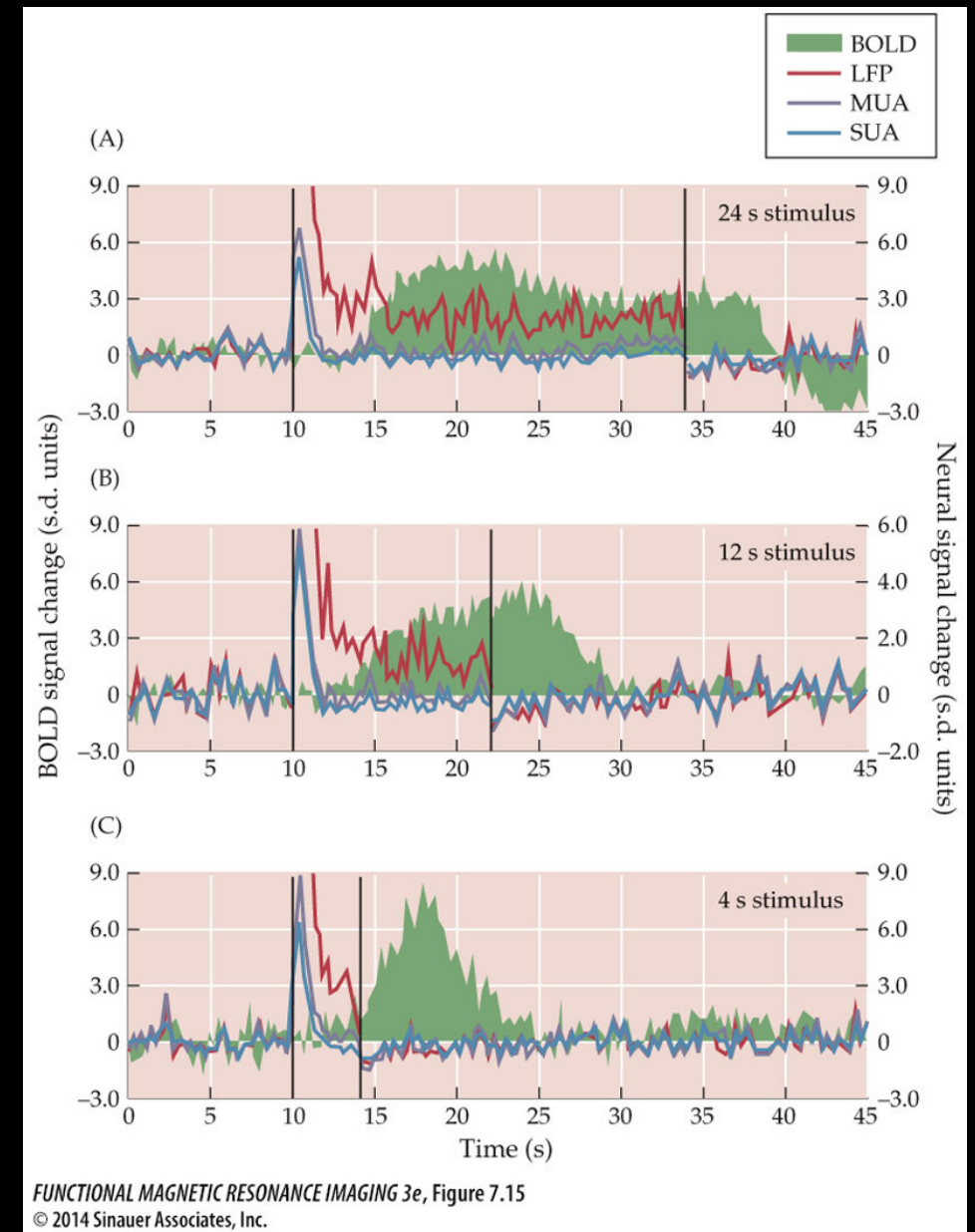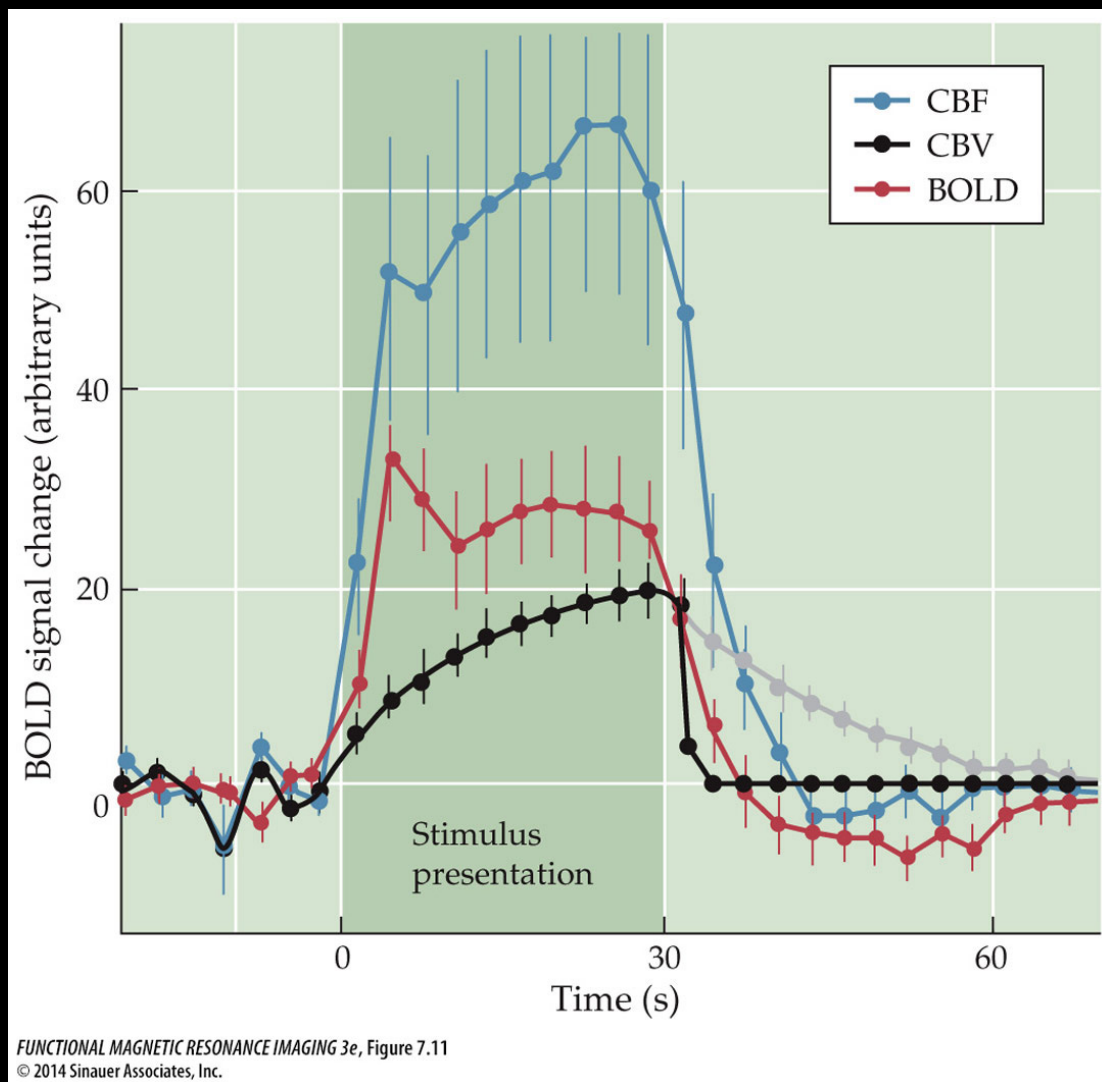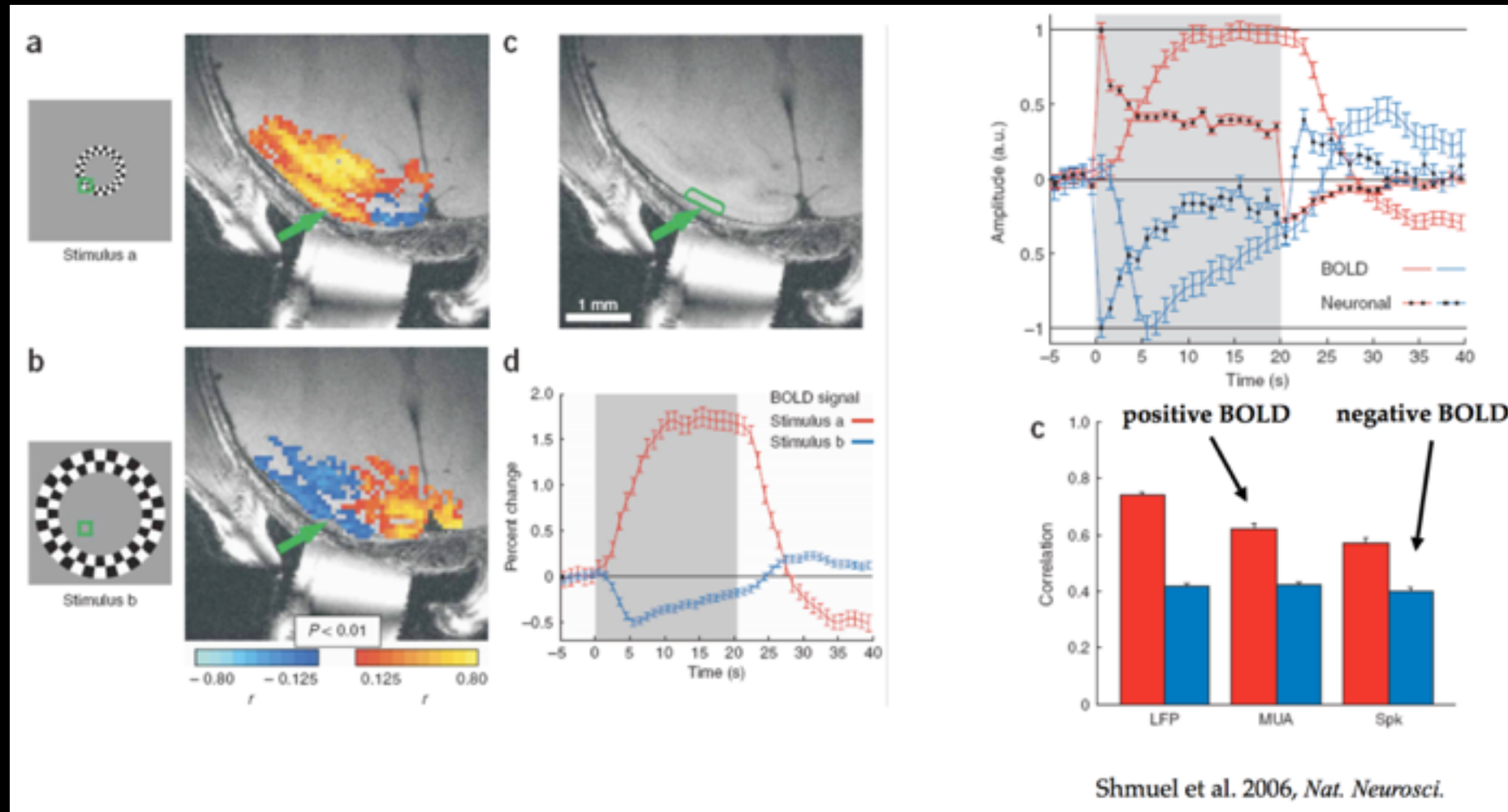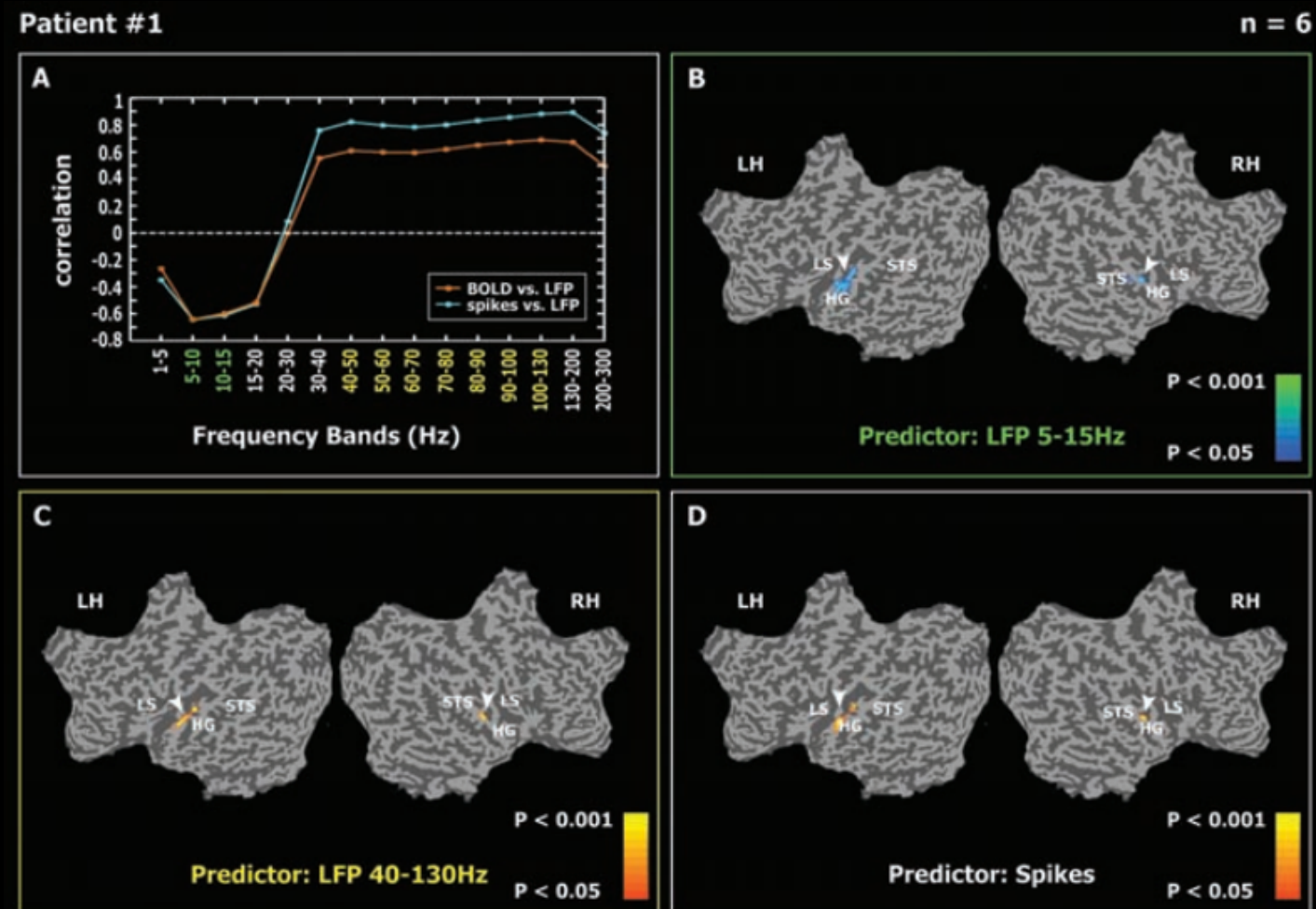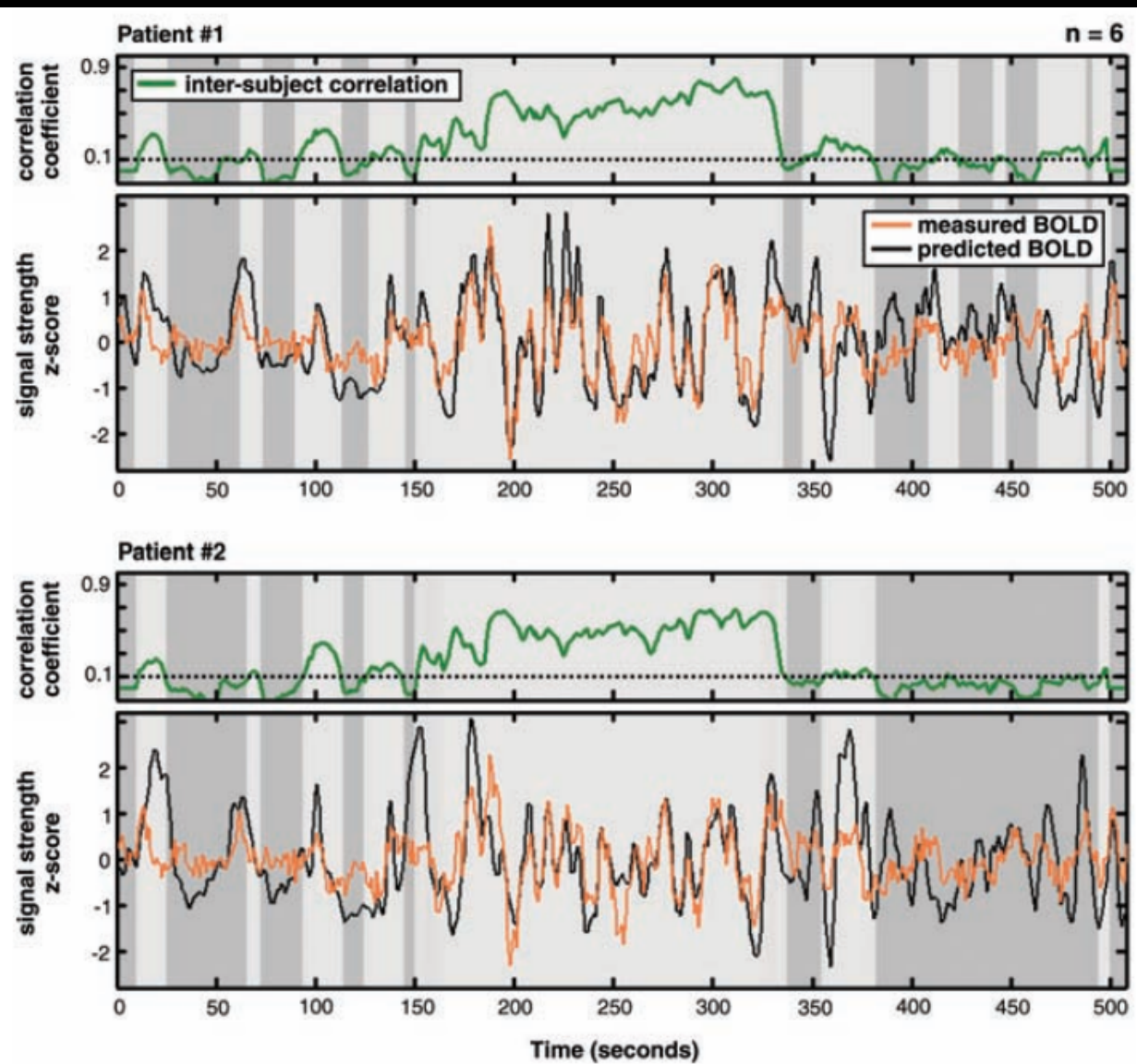
# BOLD appears to be measuring postsynaptic neural activity



Ferenczi et al., 2005 Science