BOLD fMRI:
signal source, data acquisition, and interpretation

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‘Lecture’ series

• Week 1: Biological basis: where’s the signal coming from?
• Week 2: Physical basis: what is the signal, how is it measured?
• Week 3: Imaging basics: image formation, noise, and artifacts.
• Week 4: The specific case of BOLD fMRI.
• Week 5: BOLD analysis: what’s significant and what’s not?
• Week 6: Spikes vs. BOLD: neural activity in visual areas
Imaging

• Sequence
  – Gradients: slice selection, frequency encoding, phase encoding
  – k-space
  – T1, T2 weighted; regular and fast acquisition

• Noise
  – Physiological vs. MR

• Artifacts (no slides … )
  – Folding, segmentation, Nyquist ghosts
  – Distortion vs. blurring (discussion postponed)
  – Motion artifacts
Slice selection

RF pulse: sinc in time

boxcar in frequency

With a slice-select gradient...

\[ \omega = \gamma Gz \]

\[ \omega_0 \]

\[ \Delta \omega = 42.6 \text{MHz/T} \times 10^{-4} \text{ T/cm} \]
\[ \Delta \omega = 4260 \text{ Hz/cm} \]

bw (4ms sinc) \( \sim \) 1.2kHz

\( \Rightarrow \) thk \( \sim \) 3mm

...only a slab of spins are excited
Frequency encoding within the selected slice

No gradients; all the protons precess at the same rate
Acquired signal without gradients

\[ S(t) = \int dx \rho(x) e^{i\Omega(t)} e^{-t/T^2} \]

Signal looks like homogeneous FID
Within the selected slice …

Linear gradient in X; protons precess at different rates

Typical $G_x$ value: 3 G/cm

3 T field (30000 G), 3 G/cm gradient; 20 cm field of view

$\rightarrow \pm 30/30000 = \pm .1\%$ change over FOV
Acquired signal with gradients

\[ S(t) = \int dx \, \rho(x) \, e^{i(\Omega(t)+\phi(x,t))} \, e^{-t/T2^*} \]

= \int dx \, \rho(x) \, e^{i\phi(x,t)} \, e^{-t/T2^*}

Signal is frequency encoded along one dimension
Getting to k-space
(ignoring T₂*-induced decay and magnetization history)

\[ S(t) = \int dx \, \rho(x) \, e^{i(\Omega(t) + \phi(x,t))} = \int dx \, \rho(x) \, e^{i\phi(x,t)} \]

\[ \phi_G(x,t) = - \int dt \, \omega_G(x,t) = -\gamma x \int dt \, G(t) \]

\[ k \equiv \phi / 2\pi x \]

\[ S(k) = \int dx \, \rho(x) \, e^{i2\pi kx}, \text{ an obvious inverse Fourier transform, so} \]

\[ \rho(x) = \int dk \, S(k) \, e^{-i2\pi kx} \]
How do you encode the 2nd dimension?

A brief gradient along the y direction lends a different phase to spins with different y positions.
k-space
Noise – physiological vs. RF

avg signal ~ 600
RMS(signal) ~ 10
SNR ~ 60

avg signal ~ 600
avg noise ~ 10
SNR ~ 60
SNR vs. CNR

Contrast ~ 15
Noise ~ 10
CNR ~ 1.5
SNR vs. CNR at 7T

Contrast ~ .3
Noise ~ .1
CNR ~ 3

(motion during segmented acquisition)