Reduced Flip Angle Imaging

Outline

- Determinants of Imaging Time
- TR, Saturation and Image Quality
- Reduced Flip Angle Techniques
  - FLASH (=SPGR)
  - FISP (=GRASS)
- Gradient Echoes
- Applications of Shallow Flip Imaging
- Ultra-Fast Imaging
Determinants of Imaging Time

Scan Time =

Repetition Time (TR) 
\times \text{Number of Phase Encodes} 
\times \text{NEX (Averages)} 
\times \text{Number of 3D Steps}
TR and Image Quality

Reduced TR Yields:

- Decreased Scan Time
- Increased T1 Contrast
- Reduced (Useable) T2 Contrast
- Reduced Signal to Noise Ratio
- Increased Power Deposition
- Reduced Slice Coverage
Signal and Flip Angle

Small Flip Angle

Large Flip Angle

\[ \alpha^\circ \]

transverse

longitudinal
Small and Large Flip Angle

Loss of Longitudinal Magnetization

After Small Flip Angle Excitation

After Large Flip Angle Excitation
Flip Angle and TR/T1

Relative SNR

90°
45°
20°
10°

0
0.5
1
1.5

0
0.5
1
1.5
<table>
<thead>
<tr>
<th>Large Flip Angles</th>
<th>TE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td>Proton Density</td>
<td>T2*-Weighted</td>
</tr>
<tr>
<td>T1-Weighted</td>
<td></td>
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</table>
A 180° Pulse is not used in FLASH imaging.
(examples - FLASH)

tr = 10 ms

tr = 120 ms
# TR & Flip Angle Combinations Having Similar Contrast (FLASH)

<table>
<thead>
<tr>
<th>TR</th>
<th>Flip Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>90°</td>
</tr>
<tr>
<td>2400</td>
<td>60°</td>
</tr>
<tr>
<td>1700</td>
<td>40°</td>
</tr>
<tr>
<td>750</td>
<td>20°</td>
</tr>
<tr>
<td>250</td>
<td>10°</td>
</tr>
</tbody>
</table>
T2 and T2*

T2: Transverse Magnetization Decay from Spin-Spin Interactions

T2*: Transverse Magnetization Decay from Local Magnetic Field Variations
Magnetic Susceptibility

The Extent to Which a Substance Becomes “MAGNETIZED” when Placed Within a Magnetic Field
Magnetic Susceptibility

Objects with Susceptibility Different than Air Distort the Magnetic Field
1. Equilibrium

2. 90° Pulse

3. T2* Relaxation

4. 180° Pulse

5. Spin Rephasing

6. Spin Echo
FLASH Timing Diagram

- RF
- G-Select
- G-Phase
- G-Read
- Spoiler Gradient

10 msec
FISP (GRASS) Timing Diagram

RF

G-Select

G-Phase

G-Read

10 msec
the FLASH Magnetization Cycle

1. Longitudinal Recovery

2. $\alpha^\circ$ RF pulse followed by data collection

3. Spoiling of transverse magnetization
The GRASS (FISP) Magnetization Cycle

1. Longitudinal Recovery and T2* relaxation

2. \( \alpha \) degree RF pulse and data collection

3. Longitudinal Recovery and T2* relaxation

4. \( -\alpha \) degree RF pulse and data collection
CE-FAST Sequence

RF Channel

G-Select

G-Phase

G-Read
SSFP Sequence

RF Channel

G-Select

G-Phase

G-Read
SNR vs. TR/T1
Assuming Constant Imaging Time

Relative SNR

0

0.5

1

90°

45°

20°

10°

0

0.5

1

1.5

UCLA Brain Mapping Division
fMRI: What it Offers/What it doesn’t

- Principles of functional MRI
- Performance Examples
- Theoretical Limitations
- Practical Limitations
- What Next?
- How do we get it? What does it cost?
William James (1890)

“We must suppose a very delicate adjustment whereby the circulation follows the needs of the cerebral activity.

Blood very likely may rush to each region of the cortex according as it is most active, but of this we know nothing.”
Brain “Activation” Leads to:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBF</td>
<td>Increased +ΔR1</td>
</tr>
<tr>
<td>CBV</td>
<td>Increased +ΔR2 (C+)</td>
</tr>
<tr>
<td>O₂ Utilization</td>
<td>Increased slightly?</td>
</tr>
<tr>
<td>Venous [O₂]</td>
<td>Increased -ΔR2*</td>
</tr>
<tr>
<td>Glucose Utilization</td>
<td>Increased ? Lactate</td>
</tr>
</tbody>
</table>

\[ R1 = \frac{1}{T1} \]
\[ R2 = \frac{1}{T2} \]
Gradients of several Gauss/cm may exist near deoxy-Hb-filled capillaries.
Why Does Venous $O_2$ Increase? (1)

Under normal conditions oxygen diffuses down its concentration gradient from the capillary to the brain parenchyma.
Why Does Venous O$_2$ Increase? (2)

As the brain becomes more active, the oxygen consumption increases, increasing the transluminal oxygen gradient.
Why Does Venous $O_2$ Increase? (3)

As oxygen flows across the capillary lumen it is depleted in the capillary and no further oxygen can be delivered.
Why Does Venous $O_2$ Increase?\(^{(4)}\)

The vascular system responds by increasing blood flow so that more oxygenated blood is available throughout the capillary.
Why Does Venous $O_2$ Increase? (5)

Because the blood flow is increased more oxygenated blood passes into the venous end of the capillary.
Why Does Venous $O_2$ Increase? (6)

Because the blood flow is increased more oxygenated blood passes into the venous end of the capillary.
BOLD Contrast & Field Strength

- BOLD Contrast arises from susceptibility differences
- The absolute field distortion (from BOLD) is proportional to the magnetic field strength
- The absolute change in MRI signal is proportional to both the field distortion and the signal strength.

BOLD should go as $kB_0^2$
fMRI

explores intensity variations in MR signal

intensity variations reflect venous [O2]
Gradient-Recalled Echo

Photic Stimulation -- GE Images

Signal Intensity

Seconds

Ken Kwong

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Inversion Recovery
TE=42  TR=3000
TI = 1100
Thickness=10
Inversion Recovery

Photic Stimulation -- IR Images

Signal Intensity

Seconds

off

on

off

on

2680

2740

2800

2860

0

70

140

210

280
Activation with Moving Visual Stimuli

MT / V5

V1
Contrast Response Test

0 60 120 180 240 300 360

Time (seconds)

1.6% 6.3% 25% 78% 82%

MT

V1

From R. Tootell

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Motion Sensitivity Test

From R. Tootell

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Neurovascular Coupling and fMRI latency

Pre-capillary Sphincters

Potassium Slow Potentials?
VIP release?
NO release?

Hydraulic Delay
Hemifield Alternation

- Signal Intensity
- Time (seconds)

Graph showing signal intensity over time in the right and left hemispheres.
Hemifield Alternation 20 seconds
In an LTI system, given two inputs A & B:
\[ f(A + B) = f(A) + f(B) \]
Response Latency vs. Stimulus Duration
Average of 10 recordings

Data courtesy of Robert Savoy
Brain Impulse Response

Raw Data from R. Savoy
Convolution of Impulse Responses with Stimuli

% increase over baseline

Actual Response

Convolution Model

stim

stim

stim

Time (seconds)

0 20 40 60 80 100 120

-40 -30 -20 -10 0 10 20 30 40

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Linear Systems Approach

In an LTI system, given two inputs A & B:

\[ f(A + B) = f(A) + f(B) \]
Binocular vs Monocular Activation

Baseline

Binocular

Monocular

Bino minus Mono

Extrastriate activation
Amplitude-weighted Linear Estimate
Repeated Rate Fits

(1.5 T conventional data)
Estimated vs. Actual fMRI Response

Signal Intensity

Signal Change (%)
Some Theoretical Considerations

• Study Designs:
  - Blocked
  - Single Trial

• Predicting Responses

• Sources of Variance

• Resolution Limits:
  - Temporal
  - Spatial
Blocked vs. Single Trial

Typical Blocked Design

Typical Single Trial Design

Trial Type

A B C B A C

Lights On

Lights Off

25 sec

time
Blocked Experiments

- Responses are Fairly Large
- Data are Easy to Analyze
- With Long Blocks, Time course can be Ignored
- All trials within a block are treated as Identical
Single Trial Designs

- Responses are small
- Useful contrast/noise is low
- Data are more Challenging to Analyze
- Exact Time course is Modeled or a Dependent Variable
- Suitable for Randomized Stimulus Designs
Reference Functions Used in fMRI

- Time Data
- Square Wave
- Shifted Square Wave
- Sine Function
- Shifted Sine Function
- Impulse Convolution
8 Hz checkered flash stimulation

response expressed in ‘Z’ scores

Baseline | Off 0 s | On 75 s | ≥ 10
Off 105 s | On 144 s | ≤ -5
Intravascular BOLD Effects

Capillaries

- No Diffusion
- Diffusion

Venules

- No Diffusion
- Diffusion

Effect on T2 Relaxation vs. Oxygen Saturation

Oxygen Saturation

0.5 0.75 1.0

0 40 80
Extravascular BOLD Effects (@1.5T)

Spin Echo

Effect on T2 Relaxation

Vessel Radius (µm)

Gradient Echo

Effect on T2 Relaxation

Vessel Radius (µm)
Hemifield Alternation - 20 seconds

Image Numbers

0 25 50 75 100 125 150

left
right

0.875
0.975
1.075

Basic fMRI
UCLA Brain Mapping Division

4/30/07
Some Applications of $f$MRI

Pre-surgical evaluation
Cognitive Neuroscience
Neuropsychiatric Disorders
Clinical Example
Clinical Mapping
Summary

Langua
Hand
Foot
Tongue
Geographic Imagery

Activity in Visual Cortex

States by Location
States by Name
Farm Animals

Monique Cherrier
Attentional Modulation

6 - Hand Sensory

IFG | STG | Calcarine

% Signal Change

-6
-4
-2
0
2
4
6

Attend Touch

Attend Words

4/30/07 Basic fMRI 66
Mental Rotation - Stimuli

Control

Task
Mental Rotation - Localization
Distinct Visual Pathways

Topology

- Velocity
- Direction
- Location
- Texture
- Identity
- Color
Results - Auditory Hallucinations

With Michael Green
Some Theoretical Considerations

- Study Designs:
  - Blocked
  - Single Trial
- Predicting Responses
- Sources of Variance
- Resolution Limits:
  - Temporal
  - Spatial