Rethinking How We Listen to Language: Insights from Functional Brain Mapping

Dr. Tom Christensen, Director

Department of Speech, Language & Hearing Sciences

BLAM Lab
Laboratory for Brain Imaging, Language, Attention & Memory

Left Hemisphere
Broca’s area
Wernicke’s area

Middle Frontal Gyrus
Inferior Parietal Lobule
The Brain is HIGHLY Interconnected!

DIFFUSION TENSOR IMAGING

FUNCTIONAL MRI

Broca’s area

Wernicke’s area
Brain Research in the Press

I Was a Neuroscience Guinea Pig: How Scientists Scrambled My Brain
By Lisa Katayama 11.26.07

Science of Intoxication

Thinking It Over: Neuro and Psychological Science

Randy Marsh
The average human brain contains about how many neurons?

A. one million
B. one billion
C. one-hundred billion
D. one-hundred trillion
The average human brain contains about how much **FAT**?

A. 10%
B. 50%
C. 90%
D. 99%
BRAIN QUIZ

ONE fMRI voxel measures the activity of approximately HOW MANY neurons?

64 voxels wide

64 voxels tall
ONE fMRI voxel measures the activity of approximately ONE MILLION neurons!

X: 64 voxels

Y: 64 voxels

This is ONE VOXEL in the image

blood vessels

nerve cells
BRAIN QUIZ

T or F?
You use only 10% of your brain.
FALSE!
FALSE!!
FALSE!!!
fMRI: What are we imaging?

UA’s 3-Tesla GE Scanner
fMRI: What are we imaging?

What is the physical basis of the image?
For protons of hydrogen: $^1\text{H}$

\[ \gamma = 42.58 \text{ MHz/Tesla} \]

$5 \times 10^{27}$ OF THEM!

The "R" in MRI: RESONANCE

The Larmor equation:

Resonance freq. = $\gamma \times \text{Main Field}$

Spinning & Wobbling Protons

<table>
<thead>
<tr>
<th>Field Strength (Tesla)</th>
<th>Resonance Frequency</th>
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<tbody>
<tr>
<td>1.5</td>
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What exactly are we imaging?

Outside magnetic field:
- protons are randomly oriented

Inside magnetic field:
- spins align parallel or anti-parallel to main field
- longitudinal component ($M_z$) is large
- transverse component ($M_{xy}$) is small
- only 0.0003% of protons / Tesla align with field

Main Field

Longitudinal magnetization increases

Transverse magnetization decreases

5 x 10^{27} in a 150 lb person

Spinning Protons

Outside the magnetic field:
- protons are randomly oriented
What exactly are we imaging?

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Main Field

Outside the magnetic field:
- transverse magnetization INcreases
- longitudinal magnetization DEcreases

5 x $10^{27}$ in a 150 lb person

EXCITATION PULSE!!!!
**Physics of MRI**

\[ T_1 \] = time constant for recovery of longitudinal alignment between spins

\[ TR \] (time of repetition) = time interval between excitation pulses

\[ TE \] (time to echo) = time to wait before we measure \( T_1 \)

- **T1** = time constant for recovery of longitudinal alignment between spins
- **TR** (time of repetition) = time interval between excitation pulses
- **TE** (time to echo) = time to wait before we measure \( T_1 \)

Excitation pulse @ 127.7 MHz

Highest contrast btw. WM & GM

SCAN

M

\[ M_z \]

\[ M_{xy} \]

\[ M_{\text{net}} \]
$T_2$ = time constant for decay of transverse alignment between spins

$\text{TE}$ (time to echo) = time to wait to measure $T_2$
Use T1 and T2 to Fit the Need

**T1-weighted Contrast:**
Conventional MRI (WM is white)

**T2-weighted Contrast:**
- tumors
- strokes
(WM is dark)
Magnetic Resonance Imaging (MRI) vs. functional MRI (fMRI)
The Typical fMRI Experiment

Scanning Sessions

Single 3D Volume

Anatomical & Functional Runs
The Typical fMRI Experiment

Scanning Sessions

Anatomical & Functional Runs

Subjects

Single 3D Volume

Slices
Magnet Safety

Very Powerful Magnet is on constantly!

- 1 Tesla (T) = 10,000 Gauss
- Earth’s magnetic field = 0.5 Gauss
- 3 Tesla = 3 x 10,000 ÷ 0.5 = 60,000 x Earth’s magnetic field

Thanks go to Jody Culham’s fMRI website for some of the following slides
Magnet Safety

The whopping strength of the magnet makes safety critically important.

Things can fly – even BIG things!

• We must screen subjects very carefully
• Always ON - make sure everyone is aware of the hazards
• Must develop a plan for screening every time someone enters the magnet room

Source: [http://www.simplyphysics.com/flying_objects.html](http://www.simplyphysics.com/flying_objects.html)

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Subject Safety

Anyone going near the magnet – subjects, staff and visitors must be thoroughly screened:

Subjects must have **no metal** inside the body:
- pacemakers
- aneurysm clips
- metal implants (e.g., cochlear implants)
- intrauterine devices (IUDs)
- some dental work (fillings okay)

Subjects must remove **metal** outside the body:
- jewelry, watches, piercings, even some tattoos!
- coins, etc.
- wallet
- any metal that may distort the field

Subjects must be given ear plugs or headphones (acoustic noise can reach 120 dB!)
For protons of hydrogen: $^1\text{H}$

$\gamma = 42.58 \text{ MHz} / \text{Tesla}$

5 x \(10^{27}\) OF THEM!

The "R" in MRI: **RESONANCE**

The *Larmor equation*:

Resonance freq. = $\gamma \times \text{Main Field}$

Resonance Frequency

In the big magnet, ALL protons spin at their resonant frequency

In the big magnet, ALL protons spin at their resonant frequency

Field Strength (Tesla)

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Steps in 3D Localization

Step 1. Slice Selection in Z-plane

How do we separate one slice from another?
Central Innovation: *Sequential* Gradients in the Field

1. Slice Selection in Z-plane

Add another magnetic field. Now, the protons in each slice spin at a **DIFFERENT FREQUENCY**...
The **EXCITATION PULSE** is set to the **SAME RESONANT FREQUENCY** as the protons spinning in the first slice. *(200 MHz)*

When the pulse & gradient are shut off, the protons *emit* radio signals that are then recorded.
The EXCITATION PULSE is set to the SAME RESONANT FREQUENCY as the protons spinning in the first slice. **(200 MHz)**

Emitted radio signals are then recorded by the “birdcage” around the head.
**Physics of MRI**

\[ T_1 = \text{time constant for recovery of longitudinal alignment between spins} \]

\[ TR \ (\text{repetition time}) = \text{time interval between excitation pulses} \]

\[ TE \ (\text{time to echo}) = \text{time between excit. and data acquisition} \]

**Excitation pulse** @ 127.7 MHz

**T1 Signal Strength**

- **WM**: White Matter
- **GM**: Gray Matter
- **CSF**: Cerebrospinal Fluid

**Signals Recorded**

- Highest contrast btw. WM & GM

**Repetition Time (TR) in seconds**
Steps in 3D Localization

Position in the slice

A  B  C

Position in the X-plane

-\(X\)  \(\text{---}\)  \(+X\)

200 MHz

Step 2: How do we separate signals across the Z-slice?
Steps in 3D Localization

Position in the slice

A B C

Position in the X-plane

-\(X\) \(\rightarrow\) \(+X\)

Step 2:
Add a gradient in the X-plane

Gradient

200 MHz
300 MHz
400 MHz
The **EXCITATION PULSE** is set to the **SAME RESONANT FREQUENCY** as the protons spinning in each X-slice.  

*(200, 300 MHz…)*

Emitted radio signals are then recorded by the “birdcage” around the head.
Steps in 3D Localization

Step 3. How do we get spatial information DOWN the slice?
Steps in 3D Localization

Position in the slice

A B C

X-GRADIENT

ON

OFF

O F F

Position in the Y-plane

+Y

- Y

200 MHz

Step 3. How do we get spatial information DOWN the slice?
Steps in 3D Localization

Position in the slice

+Y

Position in the Y-plane

-Y

Step 3:
Add ANOTHER gradient

NOW, also record the **phase** information in each column.
Steps in 3D Localization

1. Slice encoding (bottom to top)
2. Frequency encoding (left to right)
3. Phase encoding (front to back)

A high-res 3D MRI dataset takes about 7 minutes to collect
Where does the f-MRI signal come from?

The colors simply show the MAGNITUDE of activity across the entire brain.

But where does the activity come from?
Where does the fMRI signal come from?

ONE fMRI voxel “images” approximately 1 million nerve cells!

These neurons consume LOTS of ENERGY!

3.4 x 3.4 x 5 mm

This is ONE VOXEL in the image

64 voxels

blood vessels

nerve cells

X

Y

Z

Where does the fMRI signal come from?
fMRI: an indirect measure of neural activity

- Increase in neural activity
- Increase in local blood flow
- Rate of O₂ consumption when LBF > O₂ cons,
  - oxyHb > deoxyHb

BOLD signal = Blood Oxygen Level Dependent contrast

Blood vessels
Nerve cells

This is ONE VOXEL in the image
Deoxy-Hb and BOLD Contrast

**AT REST**
- Normal blood flow

**ACTIVATED**
- Increased blood flow
  - Oxyhemoglobin
  - Deoxyhemoglobin (reduces BOLD)

[LESS Deoxyhemoglobin INCREASES the BOLD signal]
fMRI Imaging in my Language Research

From: Christensen et al., 2011
How to strengthen your RH:

- **SING!** Read music and practice scales…
- **HIKE!** Read trail maps…
- **PAINT** or **DRAW!** Exercise your spatial localization skills…

Pathways for ATTENTIVE LISTENING
## EEG vs. Brain Imaging (MRI, fMRI, DTI)

<table>
<thead>
<tr>
<th></th>
<th>EEG</th>
<th>MRI</th>
<th>fMRI</th>
<th>DTI</th>
</tr>
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<tbody>
<tr>
<td><strong>Spatial Resolution</strong></td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td><strong>Temporal Resolution</strong></td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Type of Tissue</strong></td>
<td>Gray</td>
<td>All</td>
<td>Gray</td>
<td>White</td>
</tr>
<tr>
<td><strong>Brain Function?</strong></td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
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</table>
Where does the fMRI signal come from?

Angelo Mosso
c. 1890

“The moment emotional or intellectual activity began, down went the balance at the head end, in consequence of the redistribution of blood in his system.”
Where does the fMRI signal come from?

Red: middle cerebral artery
Veins are in black