MR Acquisition: OVERVIEW of Control Equip and Experimental Setup, Dealing with Anatomicals
Additional Equipment

- Software: E-prime, pyEPL
- Time-Line:
  - Control Stimulus
  - Monitor Response
  - Synchronize timing with MRI
# fMRI Study Time

<table>
<thead>
<tr>
<th>Step</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Design</td>
<td></td>
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<tr>
<td>Scanning</td>
<td></td>
</tr>
<tr>
<td>- Setup</td>
<td>15-20 min</td>
</tr>
<tr>
<td>- Scans</td>
<td>45 min to 1 hr</td>
</tr>
<tr>
<td>- Take down</td>
<td>15 min</td>
</tr>
<tr>
<td>Preprocessing</td>
<td>&lt;2 hr/subject</td>
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<tr>
<td>Statistical Analysis</td>
<td>variable</td>
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fMRI Study – All Data

Raw Data ~200 mBytes
Motion Correction ~180 mBytes
Other Corrections ~180 mBytes each possibly
Spatial Normalization ~ 30 mBytes
Statistical Analysis
  • Statistical Parametric Image (128x128x20) < 1 MByte
  • Statistical Parametric Map (2x SPI) > 1 MByte

Typical Data per subject can be 0.5-1.0 gBytes
Can be as high as 4 GB per subject
Slice Terminology

- **Slice Thickness**: e.g., 6 mm
- **Number of Slices**: e.g., 10
- **Matrix Size**: e.g., 64 x 64
- **Field of View (FOV)**: e.g., 19.2 cm
- **In-plane resolution**: e.g., 192 mm / 64 = 3 mm
- **VOXEL (Volumetric Pixel)**: 3 mm x 3 mm x 3 mm
MRI vs. fMRI

**MRI**
- high resolution (1 mm)
- one image

**fMRI**
- low resolution (~3 mm but can be better)
- many images (e.g., every 2 sec for 5 mins)

**fMRI**
Blood Oxygenation Level Dependent (BOLD) signal
indirect measure of neural activity (T2*)

↑ neural activity ➔ ↑ blood oxygen ➔ ↑ fMRI signal
Spatial Registration

• We use spatial registration to align images
  - **Motion correction** (realignment) adjusts for an individual’s head movements.
  - **Coregistration** aligns two images of different modalities from the same individual.
  - **Normalization** aligns images from different people.
Within-subject registration

- With-in subject registrations
  - Assumption: same individual, so there should be a good linear solution.

Motion correction

Coregistration

Registration of the fMRI scans (across time)

Registration across modality (e.g. T2* and T1 image)
By measuring and correcting for translations and rotations, we can adjust for an object’s movement in an image.

- 6 Parameters: translation and rotation each in 3 dimensions.
Motion Correction

Motion correction aligns all in time series.

Translations and rotations only
- 6 parameters (X,Y,Z; yaw, pitch, roll)
- ‘rigid body registration’
- Assumes brain size and shape identical across images.
Motion correction cost function

- Motion correction uses least squares to check if images are a good match (aka minimum sum of squares).
- Smaller difference\(^2\) = better match (‘least squares’).
- Notes about difference\(^2\)
  - Any number squared is positive: does not care about direction of error.
  - Large error penalized much more than small error (e.g. \(2^2=4\), \(3^2=9\)), whereas using absolute value as cost function would not be so biased between large and small errors.
- Iterative: moves image a bit at a time until match is worse.
Local Minima

Search algorithm is iterative:
- Adjust image a little bit.
- Test cost function
- Repeat until cost function does not get better.

Problem: local minima

Solution: ensure starting estimate is accurate
- For motion correction: only small head movements
- For coregistration: both images start in good alignment
- For normalization: similar origin and rotation as template
Coregistration

- Coregistration is more complicated than motion correction
  - Rigid body not enough:
    - Size differs between images (must rescale: zooms and interpolation).
    - fMRI scans often have spatial distortion not seen in other scans (must skew: shears).
  - Least squares cost function will fail: relative contrast of gray matter, white matter, CSF and air differences between images.
Affine Transforms (aka linear, geometric)

Translation, Rotation, Zoom, Shear

12 Parameters: translation, rotation, zoom and shear each in 3 dimensions.
Coregistration

- Coregistration is used to align images of different modalities from the same individual.
- Uses ‘mutual information cost function’: Note unaligned images have messy joint histograms.
- Uses entropy reduction instead of variance reduction as cost function.
Coregistration

- Note original joint histogram (prior to coregistration) is noiser than the final joint histogram (after coregistration).
- Used within individual, so linear transforms should be sufficient.
- Typically 12 parameters (translation, rotation, zooms, shear each in 3 dimensions).
- Though note that different MRI sequences create different non-linear distortions.
Between-subject: Normalization

- Normalization: align images from different people (align everyone to a template image)
Why normalize?

- Stereotaxic coordinates analogous to universal reference space
  - Universal description for anatomical location
  - Allows other to replicate findings
  - Allows between-subject analysis: crucial for inference that effects generalize across humanity.

Group analysis

Subject1
Subject2
Subject3
Subject4
Subject5
Normalization

• Normalization attempts to register scans from different people.
• We align each person’s brain to a template.
  – Template often created from multiple people (so it is fairly average in shape, size, etc).
  – We typically use template that is in the same modality as the image we want to normalize
    • Therefore, variance cost function.
• If different groups use similar templates, they can talk in common coordinates.

Popular MNI Template based on T1-weighted scans from 152 individuals.
Common templates

- SPM uses modality specific template
  - MNI T1 template, plus custom templates
- By default, FSL uses MNI T1 template for all modalities
  - Requires intra-modal cost functions (e.g. mutual information)
Templates

• Our coordinate system using anterior commissure as origin developed by Talairach and Tournoux (1988) who created atlas based on histological slices from one 69-year old woman.
  - Single brain may not be representative
  - No MRI scans from this woman

• Modern templates are generated from a group of MRI scans that are approximately aligned to images from the Montreal Neurological Institute.
  - MNI space slightly different from T&T atlas (larger in every dimension).
  - Therefore, proper to refer to “Talairach and Tornoux” coordinates and “MNI space”.
Individual Differences

No gender or racial differences between brains have been measured.

However, significant and systematic differences between East vs West, Asian vs Caucasian have been constructed.
Affine Transforms

- Co-linear points remain co-linear after any affine transform.
- Transform influences entire image.
Spatial Processing

- Non-linear transforms can match features that could not aligned with affine transforms.
- SPM uses basis functions.
Nonlinear functions and normalization

Scans from 5 people: nonlinear helps alignment

Linear Only

Linear + Nonlinear
Regularization

- Regularization penalizes bending energy
- What is the best way to graph points with a line? Heavy regularization is a poor fit, light regularization can overfit (local distortion, influenced by noise).
Regularization

- Regularization is a parameter that you can adjust that influences non-linear normalization.

[Images of grid patterns showing medium and little regularization]

http://www.fmri.ox.ac.uk/fsl/fnirt/
ARTIFACTS

Hardware Issues  e.g. calibration, power stability
Software problems  e.g. programming errors
Physiological phenomena  e.g. blood flow
Physics limitations  e.g. Gibbs and susceptibility
Motion Artifacts

Bright noise or repeating densities usually oriented in the phase direction.

Extend across the entire FOV, unlike truncation artifacts that diminish quickly away from the boundary causing them.

Examples: Arterial pulsations, CSF pulsations, swallowing, breathing, peristalsis, and physical movement.
Motion Artifacts

Mitigation:

Arterial and CSF pulsation artifacts can be reduced with flow compensation and cardiac gaiting.

Spatial presaturation can reduce some swallowing and breathing artifacts and arterial pulsations.
Motion Artifacts

Mitigation (cont.):
Surface coil localization can reduce artifacts generated at a distance from the area of interest.
Next time More detailed theory on Spatial Registration and Atlases.

Now tho.. practice on BET and registration
Aliasing or "Wrap-around"

Occurs when the field of view (FOV) is smaller than the body part being imaged causing the region beyond to project on the other side of the image.

Caused by undersampling in the phase or (rarely) frequency direction.

May occur in end slices of a 3D acquisition.
Aliasing or "Wrap-around "
Aliasing
Aliasing or "Wrap-around"

Correction:
Increase the FOV (decreases resolution).
Oversampling the data in the frequency direction (standard) and increasing phase steps in the phase-encoded direction – phase compensation (time or SNR penalty).
Swapping phase and frequency direction so phase is in the narrower direction.
Use surface coil so no signal detected outside of FOV.
Field inhomogeneity

Types:
Main magnetic field
RF coil inhomogeneity
Dielectric effects – worst at 3T+

May cause variation in intensity across image
May cause non-uniform fat suppression
Field inhomogeneity – Bo
Field inhomogeneity - Dielectric
Field inhomogeneity

Mitigation:
Shimming, area of interest in near isocenter
Use Fat suppression
Coil – Use volume vs. surface coil, allow space between coil and body.
Dielectric – use phased array coils, software compensation
RF Overflow Artifacts (Clipping)

Causes a nonuniform, washed-out appearance to an image.

Occurs when the signal received from the amplifier exceeds the dynamic range the analog-to-digital converter causing clipping.

Autoprescanning usually adjusts the receiver gain to prevent this from occurring.
RF Overflow Artifacts

ANALOG FID

DIGITIZED FID

3 BIT ADC

SIGNAL CUT-OFF
Moire Fringes

Moire fringes are an interference pattern most commonly seen when doing gradient echo images.

One cause is aliasing of one side of the body to the other results in superimposition of signals of different phases that add and cancel. Can also be caused by receiver picking up a stimulated echo.

Similar to the effect of looking though two window screens.
Moiré Fringes
Central Point Artifact

A focal dot of increased or decreased signal in the center of an image.

Caused by a constant offset of the DC voltage in the amplifiers.
Central Point Artifact
Central Point Artifact

Correction:
Requires recalibration by engineer
Maintain a constant temperature in equipment room for amplifiers.
Quadrature ghost artifact

Another amplifier artifact caused by unbalanced gain in the two channels of a quadrature coil. Combining two signals of different intensity causes some frequencies to become less than zero causing 180 degree “ghost.”
Quadrature ghost artifact
Susceptibility Artifacts

Variations in the magnetic field strength that occurs near the interfaces of substance of different magnetic susceptibility such as ferromagnetic foreign bodies.

Causes dephasing of spins and frequency shifts of the surrounding tissue.
Susceptibility Artifacts

Worst with long echo times and with gradient echo sequences.
Worst at higher magnetic field strength.

Less with fast/turbo spin echo sequences.
Susceptibility Artifact 1
Susceptibility Artifact 2
Zebra Artifacts

Band-like, usually oblique stripes.

Data in the K-space array will be missing or will be set to zero by the scanner or an electrical spike may occur as from static.

The abrupt change from signal to no signal or normal signal to high signal results in artifacts in the images.
Zebra Artifacts

Diagram showing frequency and phase with a frequency spectrum and a phase spectrum.

The image on the right shows an MRI scan with zebra-like artifacts.
Eddy Current Artifacts

Varying magnetic field from gradients can induce electrical currents in conductors such as the cryostat causing distortion of the gradient waveforms. Particularly a problem with echo-planar imaging that uses strong, rapidly changing gradients.
Eddy Current Artifacts

Image courtesy of http://www.mr-tip.com/
Comprehensive Receiving coils

- 7 standard configuration:
  - QD head coil
  - QD Neck Coil
  - QD Body Coil
  - QD Extremity Coil
  - Flat Spine Coil
  - Breast Coil
Surface Coils
RF Coil Uniformity and SNR

(1) two surface coils on opposite sides in phase.
(2) two surface coils out of phase.
(3) single surface coil on right side. (largest SNR)
(4) head coil. (most uniform SNR)

Figure 5.7 from textbook.
Types of Artifacts

Noise
Aliasing
Black Boundary Artifact
Gibbs or Truncation Artifact
Zipper Artifact (RF noise)
Motion Artifacts (Phase direction)
Field inhomogeneity
Moire Fringes
Central Point Artifact
Quadrature Ghost
Susceptibility Artifact
Zero-fill (Zebra Artifact)--Spiking
Eddy Current Artifacts
Noise --Random
Johnson noise, shot noise, thermal noise
Random Noise

Maintenance-- maintenance maintenance.
Slice-overlap (cross-slice) Artifacts

Loss of signal seen in an image from a multi-angle, multi-slice acquisition.

Same mechanism as spatial presaturation for reduction of motion and flow artifacts.

Example: Two groups of non-parallel slices in the same sequence, e.g., L4-5 and L5-S1. The level acquired second will include spins that have already been saturated.
Slice-overlap (cross-slice) Artifacts
Slice-overlap Artifacts
Slice-overlap Artifacts

Correction:
Avoid steep change in angle between slice groups.
Use separate acquisitions.
Use small flip angle, i.e. GE sequence
Cross-talk Artifact

Result of imperfect slice excitation, i.e. non-rectangular, of adjacent slices causing reduction in signal over entire image. May be reduced by using gap, interleaving slices and optimized (but longer) rf pulses.
Cross-talk Artifact

Slice Profiles

Cross Talk