DECLARATION OF CONFLICT OF INTEREST OR RELATIONSHIP

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I have no conflicts of interest to disclose with regard to the subject matter of this presentation.
Artifacts in fMRI

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What I can tell you about:

- PET imaging
- Radionuclide production
- PET data analysis
- fMRI data analysis
- Coregistration
- Morphometry measures

Not so much:
MRI physics, pulse sequences, data acquisition
What is an Artifact?

To neuroscientists, this brain looks funny.

To Wisconsin Badger fans, the brain obscures the logo.

An artifact is anything that prevents you from seeing what you want to see.
What is the Signal?

Timeseries - filtered_func_data (face/voice)
What is the goal?

1.4% signal change

23.0% signal change
Big-picture goal

- Is this region activated? (localization)
- How much? (effect size)
- Are you sure? (reliability)

stimulus 1
(\textit{Go})

stimulus 2
(\textit{No go})
Artifact Sources

- **Physiological**
  - cardiac, respiratory motion
  - subject movement
  - poor intersubject alignment
  - B-field susceptibility (dropout)
  - foreign objects

- **Scanner**
  - SNR
  - B-field inhomogeneity
  - detector coil sensitivity
  - reconstruction tradeoffs
  - slice-timing (2D) effects

\[ t = \frac{\text{effect}}{\text{variance}} \]
A Scientific Experiment

Before
- measure twice, cut once

During
- look at your data. with your eyes.

After
- pre-processing: modeling and removing variance
- data analysis: modeling and discovering signal
The single biggest artifact source
Being Clever Ahead of Time

**Before**

- Learn a package
  - provides an orderly introduction to analysis.
- Software programming skills
- File format conversion
- Experimental paradigm
  - event-related paradigms can isolate stimulus, HR

**Acquisition sequence**

- Collect enough data
  - multispectral anatomicals (T1, T2, PD, ...)
  - field map
  - physiological (cardiac, respiratory, skin conductance, eye tracking)
  - estimator for HRF (e.g. motor response)
Post-hoc Corrections

- Some folks call it image processing...
  - spatial registration
  - field map correction
  - slice time correction
  - motion correction
  - smoothing - spatial, temporal

- These corrections are ignorant of the experimental model.
EPI Dropout (susceptibility) artifact

phase dispersion $\Rightarrow$ signal loss
EPI susceptibility artifact

clever ahead of time: optimize acquisition parameters

TE = 30 ms
4mm thick slices

TE = 20 ms
2mm thick slices

courtesy of Andy Alexander
EPI dropout artifact

T1

EPI

T1

EPI

EPI

T1

EPI
EPI registration – tread carefully
EPI registration: indirect approach

T1, coplanar with EPI

T1

EPI

assume no movement

register
Typical acquisition sequence

Goal: spatial alignment
Hurdle: movement ~ time

scout  shim  field-map  task1  task2  task3  ...  taskN  DTI  T1  T2
Off to a bad start

Remove first 3-5 frames:
- delete from series
- mark via GLM software
- assign to a unique condition
The magnetic field is not uniform, leading to misplaced signal, since recording/reconstruction assumes a uniform gradient.

- 3T => worse

Nonuniformities are object-dependent.

- Largest source of $B_0$ inhomogeneity:
  - air-tissue interfaces => susceptibility differences

Different acquisition sequences may have different affect.

- EPI data (Gradient Echo) most affected (fMRI, DTI)
- Spin Echo affected little

Luckily, this can be modeled and corrected...

- But, a separate measurement is required.
- 2 scans with different TEs (e.g. 8, 11 msec), minimal distortion.
For a linear field offset, phase error accumulates linearly.
Cumulative phase errors cause a shift in position.
Distortion (Fieldmap) Correction

Strategy: Collect two gradient echo images at short but different echo times.

- Unwrap the phase.
- Phase-difference proportional to the pixel-offset along the phase-encode axis.
- Resample the EPI image to correct for the offset.

Field Map Correction

courtesy of John Ollinger
Magnitude of correction depends on the magnitude of the susceptibility artifact, which depends on the size of the sinuses.

- Larger in men than women.
- Larger in adults than children

Although the magnitude of the correction is often small, it can reduce confounds between gender, age and susceptibility.

- It cannot recover missing data from the dropout region.

courtesy of John Ollinger
Inhomogeneity Correction

original

inhomogeneity corrected

Difference (~ bias field)

joint histogram
Inhomogeneity Correction

- Increase gradient magnetic field strength.
- Decrease echo time.
- Smaller pixels (better resolution).
- Phase encoding.
- Postprocessing.
Slice-time Correction

Make all slices appear to have been acquired at the same time.

A “reference” HRF should look the same in all slices.

More important for longer TR. Usually best prior to motion correction.
Motion Artifacts

Sources
- Subject motion
- Peripheral movement (changes B-field)
- Respiration, cardiac

Magnitude / Importance
- A significant fraction of the fMRI signal!

Model
- Framewise 3D volumetric
  - Rigid body (translation, rotation)
  - Ignores intraframe motion
- Assumes only small movement

Correlation between motion, stimulus
- Correcting motion can attenuate activation signal
- Motion estimates can be incorporated into GLM
looking for Δ signal 1-5% (at best!)

30% overlap
(1-2 mm)
in-plane motion: easy

between-plane: messy

Motion Correction: Subject Motion

t=0


t=later
Combining scan runs

run 1

run 2

[Graph showing multiple series over time with callouts for run 1 and run 2]
Motion Artifact: Typical pattern

Single subject data

axial

original

motion corrected

effect size

coronal

Phantom (simulated) data

block design

event-related design
Motion Correlated with Stimulus

Johnstone T et al., “Motion Correction and the Use of Motion Covariates in Multiple-Subject fMRI Analysis”, *Hum Brain Mapp* 27:779–788, 2006.
Motion Parameters:

How can we use this information for Good?

- Apply motion correction: reslice each 3D volume
  - "standard" approach
  - loss of sensitivity if motion correlated with activation

- Use parameters as covariates in GLM
  - may increase sensitivity
  - more flexible data analysis
  - small loss of degrees of freedom in GLM
Block design:
- if motion correlated with stimulus, “standard” reslice best

Event-related design:
- motion parameters in GLM usually work well.

T Johnstone et al., “Motion Correction and the Use of Motion Covariates in Multiple-Subject fMRI Analysis”, *Hum Brain Mapp* 27:779 –788, 2006.
Motion Correction at Work

Decrease in Maximum T value

Motion Artifact in Block Design

Processing Pathway

Motion artifact
Smoothing - spatial

- Increase S:N
  - Objects similar in size to smoothing kernal emphasized
  - Matched filter theorem
- Manage imperfect registration
- Fulfill “Gaussian random field” assumption
artifact?

not any more
EPI time series
- Spatial smoothing removes small (uninteresting) clusters
- Mild temporal smoothing beneficial:
  - trend removal
  - high-pass filter
  - most versatile if left until GLM stage

Parameter estimate (cluster) maps
- more versatile for analysis
- changes fitted results

Smoothing – when?
Dropping one “superstar” performer causes large drop in group t-value.

- Multi-subject or 2nd-level analysis
- Subject-to-subject variance dominates
- Most analysis assume:
  - Similar within-subject variance
  - Similar data acquisition, analysis

From work by Pradeep Chilakamarri
Software Recommendations

- **fMRI - specific**
  - AFNI, FSL, SPM have largest market share, similar results
  - Two-step procedure for selecting software:
    - Find the smartest person in your lab.
    - Use what they use.

- **Scripting**
  - bash
    - fast, easy, universal
    - idiosyncratic, hard to distribute
  - Python
    - versatile, extensible, good for distribution
    - mostly universal, moderate learning curve
  - Matlab, IDL
  - sed & awk? You don’t need my advice.

- **Other handy tools:**
  - R [http://www.r-project.org/]
  - fmristat [http://www.math.mcgill.ca/keith/fmristat/]
  - NiPy [http://neuroimaging.scipy.org/]