Model-based fMRI

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Kerstin Preuschoff
To model or not to model

GLM  
DCM  
Classification  
Multivariate Bayes
fMRI uses models at different stages

- Hemodynamic response (hrf)
- Activation levels
- Time courses
- Connectivity
- t-tests
Overview

• Categorical designs
  Subtraction - Pure insertion, evoked / differential responses
  Conjunction - Testing multiple hypotheses

• Parametric design
  Linear - Adaptation, cognitive dimensions
  Nonlinear - Polynomial expansions, neurometric functions

• Factorial designs
  Categorical - Interactions and pure insertion
  Parametric - Linear and nonlinear interactions
Parametric designs

- Vary the stimulus-parameter of interest on a continuum, in more than 2 steps,
  - e.g., ratings on a scale of 1-7; amount of reward received
- Relate measured BOLD signal to this parameter
- Many possible tests for such relations:
  - Linear, Nonlinear: Quadratic/cubic/etc. (polynomial expansion)
- Model-based regressors (e.g., predictions from behavioral models)
Model-based fMRI

- Applying quantitative computational models to generate regressors of interest beyond stimulus inputs and behavioral responses

- Goal: uncover hidden variables or processes
Model-based fMRI: questions answered

- How (i.e., by activation of which areas) does the brain implement a particular cognitive process?

[Image of participant response graph]
1. Basic recipe for model-based fMRI

2. Using model-based regressors in the GLM
When *not* to decide on a model

1. Hypothesis

2. Experimental design (e.g., event-related)

3. Data collection

4. No effect for event-related analysis :(

5. **Find a computational model to track hidden variables**
When to decide on a model

1. Hypothesis

2. **Find a computational model to track hidden variables**

3. Experimental design (e.g., event-related)

4. Data collection

5. *No effect for event-related analysis :*(
Model-based fMRI

1. Decide on a model
   - This should happen *before* you run the experiment.
   - Start with a research question and choose a model that adequately addresses this question.
   - Design your experiment with this model in mind.
   - E.g., reinforcement learning model, hierarchical bayesian model.

[Diagram of participant response]
Model-based fMRI

1. Decide on a model
   - Reinforcement learning model

Participant response
Model-based fMRI

2. Pass individual subject trial history to model

\[
\delta = R_{t+1} + \gamma V_{t+1} - V_t
\]

\[
V_{t+1}^A = V_t^A + \alpha \delta
\]
Model-based fMRI

3. Find best-fitting parameters of the model (e.g., learning rate) to behavioral data

4. Generate
   a. parametric modulators (first level)
   b. model-based time series (first level)
   c. subject-specific parameters (e.g., second level, DCM)
Model-based fMRI

5. Convolve time series with hemodynamic response function

Adapted from O’Doherty et al., (2007)
Model-based fMRI

6. Regress against fMRI data

Hampton et al., (2006)
Model-based fMRI

1. Decide on a model
2. Pass individual subject trial history to model
3. Find best-fitting parameters of model to behavioral data
4. Generate parametric modulators & model-based time series
5. Convolve time series with hemodynamic response function
6. Regress against fMRI data
From classic design to model based fMRI

1. Classic event/block design

2. Adding parametric regressors

3. Model-based design
Model-based fMRI: comparisons

- Classical event/block design
Model-based fMRI: comparisons

- Classical event/block design
Model-based fMRI: comparisons

- Parametric regressors
Model-based fMRI: comparisons

- Parametric regressors
Model-based fMRI: comparisons

- Parametric regressors
How do we construct regressors that correspond to cognitive processes and use them in SPM?

4. Generate

   a. parametric modulators (first level)
   b. model-based time series (first level)
   c. subject-specific parameters (e.g., second level, DCM)
How do we construct regressors from a time series and use them in SPM?

Sample time-series at points of interest (e.g., participant response)

Enter as parametric modulation for condition ‘participant response’
How do we construct regressors from a time series and use them in SPM?

Convolve time series with hemodynamic response function
How do we construct regressors from a time series and use them in SPM?

Convolve time series with hemodynamic response function

- sample time series at the same rate as the basis functions

- convolve with the basis functions $\text{SPM.xBF.bf}$

- sample at TR (i.e., one sample per functional volume)

- add to design matrix as (multiple) regressor(s)
How do we construct regressors from a time series and use them in SPM?

Convolve time series with hemodynamic response function

- add to design matrix as (multiple) regressor(s)
How do we include individual model parameters?

e.g., enter as covariates at the second level
Model-based fMRI recipe

1. Decide on a model (*before* finishing your experimental design)

2. Pass individual subject trial history to model

3. Find best-fitting parameters of model to behavioral data

4. Generate parametric modulators & model-based time series

5. Convolve time series with hemodynamic response function

6. Regress against fMRI data
Design efficiency

- Regressors and design matrix not fully specified before data collection.

- To estimate design efficiency:
  - Simulate behavioral data, conduct behavioral pilot study
  - Obtain simulated/pilot time course from the model
  - Optimize design efficiency
Simulated data for estimating design efficiency

\[ p_a(t, \text{cue}) = \frac{e^{Q_a(t, \text{cue})/\beta}}{e^{Q_a(t, \text{cue})/\beta} + e^{Q_b(t, \text{cue})/\beta}} \]

\[ Q_a(t + 1, \text{cue}) = Q_a(t, \text{cue}) + \eta(R(t) - Q_a(t, \text{cue})) \]
Simulated data for estimating design efficiency
Model-based fMRI: design efficiency

- Model based fMRI
Model-based fMRI: comparisons

- Model based fMRI

![Graph showing time domain regressors for Condition and parameters over time (in seconds)]
Model-based fMRI recipe

1. Decide on a model
2. Pass individual subject trial history to model
3. Find best-fitting parameters of model to behavioral data
4. Generate model-based time series
5. Convolve time series with hemodynamic response function
6. Regress against fMRI data