Single-Session Analysis

Voxel-wise single-subject analysis

FMRI data → Preprocessed data → Voxel time-series data → Design matrix

Stimulus/task timings → GLM → Single-subject effect size statistics

Motion correction → High-pass filtering → Spatial smoothing

Contrast → Statistic Image → Thresholding → Significant voxels/clusters

Effect size statistics

Effect size statistics
FMRI Modelling and Statistics

• An example experiment
• Multiple regression (GLM)
• T and F Contrasts
• Null hypothesis testing
• The residuals
• Thresholding: multiple comparison correction
Two different views of the data

A “smallish” number of volumes

A large number of time series
FMRI Modelling and Statistics

- An example experiment
- Multiple regression (GLM)
- T and F Contrasts
- Null hypothesis testing
- The residuals
- Thresholding: multiple comparison correction
An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
An example experiment

An FMRI adaptation of a classical PET experiment

• Three types of events
• 1st type: Word Generation

Noun is presented

Car

Screen

Verb is generated

Drive

Healthy Volunteer

Scanner

Bed
An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation

Noun is presented

Verb is generated

Healthy Volunteer

Scanner

Bed

Screen

Door
An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing

Verb is presented

Walk

Screen

Verb is repeated

Walk

Scanner

Healthy Volunteer

Bed
An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing

![Diagram showing the process of verb presentation and repeated reading in an FMRI experiment.](image)
An example experiment
An FMRI adaptation of a classical PET experiment

• Three types of events
• 1st type: Word Generation
• 2nd type: Word Shadowing
• 3rd type: Null event
An example experiment
An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing
- 3rd type: Null event

Crosshair is shown

Scanner

Bed

Healthy Volunteer

Screen
An example experiment

An FMRI adaptation of a classical PET experiment

- Three types of events
  - 1st type: Word Generation
  - 2nd type: Word Shadowing
  - 3rd type: Null event
- 6 sec ISI, random order
An example experiment
An FMRI adaptation of a classical PET experiment

- Three types of events
- 1st type: Word Generation
- 2nd type: Word Shadowing
- 3rd type: Null event
- 6 sec ISI, random order
- For 24 events of each type
FMRI Modelling and Statistics

• An example experiment
• **Multiple regression (GLM)**
• T and F Contrasts
• Null hypothesis testing
• The residuals
• Thresholding: multiple comparison correction
Building a model

Our task is now to build a model for that experiment

What is our predicted response to the word generation events?
Building a model

Our task is now to build a model for that experiment.

What is our predicted response to the word generation events?

Stick-function at each occurrence of a “generation event”

Well, hardly like this...
Building a model

Our task is now to build a model for that experiment

What is our predicted response to the word generation events?

That looks better!
Building a model

Our task is now to build a model for that experiment.

What is our predicted response to the word generation events?

And this is the prediction for the whole time-series.
Building a model

Our task is now to build a model for that experiment

What is our predicted response to the word generation events?

So, if we spot a time-series like this
Building a model

Our task is now to build a model for that experiment.

What is our predicted response to the word generation events?

And then check it against our prediction, we can conclude that this pixel is into word generation.
Building a model

Our task is now to build a model for that experiment.

And we can do the same for the word shadowing events?

This time we used the onset times for the shadowing events to get the predicted brain response for those.
Building a model

Our task is now to build a model for that experiment

And we can do the same for the word shadowing events?

And we can look for voxels that match that
Formalising it: Multiple regression

\[ \text{Observed data} \approx \beta_1 + \beta_2 \cdot \]

Predicted responses: "Regressors"

Word Generation

Word Shadowing

Unknown "parameters"
Slight detour: Making regressors

Event timings at “high” resolution

Convolve with HRF

Predictions at “high” resolution

Sub-sample at $T_R$ of experiment

Regressor
Estimation:
Finding the “best” parameter values

- The estimation entails finding the parameter values such that the linear combination "best" fits the data.

Let’s try these parameter values

\[ \approx \beta_1 \cdot 0.5 \quad + \beta_2 \cdot 0.5 \]
Estimation:
Finding the “best” parameter values

• The estimation entails finding the parameter values such that the linear combination ”best” fits the data.

Hmm, not a great fit

\[ \beta_1 \approx 0.5 \]

\[ + \beta_2 \cdot 0.5 \]
Estimation: Finding the “best” parameter values

- The estimation entails finding the parameter values such that the linear combination "best" fits the data.

\[ \approx \beta_1 \cdot 0 + \beta_2 \cdot 1 \]

Oh dear, even worse
Estimation:
Finding the “best” parameter values

• The estimation entails finding the parameter values such that the linear combination ”best” fits the data.

But that looks good

Word Generation

\[ \approx \beta_1 + \beta_2 \cdot 1 \cdot 0.4 \]
Estimation: Finding the “best” parameter values

• The estimation entails finding the parameter values such that the linear combination ”best” fits the data. And different voxels yield different parameters.
Estimation:
Finding the "best" parameter values

- The estimation entails finding the parameter values such that the linear combination "best" fits the data.

\[ \approx \beta_1 \cdot \ -0.04 \quad + \beta_2 \cdot \ -0.03 \]

And different voxels yield different parameters.
One model to fit them all

[\begin{bmatrix}
1.10 \\
1.02
\end{bmatrix}]

\[\beta_1\]

\[\beta_2\]

[\begin{bmatrix}
1.04 \\
-0.10
\end{bmatrix}]

[\begin{bmatrix}
-0.04 \\
-0.03
\end{bmatrix}]

Time

Model
And we can also estimate the residual error

Difference between data and best fit: “Residual error”

Residual errors
And we can also estimate the residual error

\[ \begin{bmatrix} 1.10 \\ 1.02 \end{bmatrix} \]

\[ \begin{bmatrix} 1.04 \\ -.10 \end{bmatrix} \]

\[ \beta_1 \]

\[ \beta_2 \]

\[ \sigma^2 \]
Summary of what we learned so far

- The “Model” consists of a set of “regressors” i.e. tentative time series that we expect to see as a response to our stimulus
- The model typically consists of our stimulus functions convolved by the HRF
- The estimation entails finding the parameter values such that the linear combination of regressors ”best” fits the data
- Every voxel has its own unique parameter values, that is how a single model can fit so many different time series
- We can also get an estimate of the error through the “residuals”
General Linear Model (GLM)

- This is placed into the General Linear Model (GLM) framework

\[ y = X \beta + e \]

- Data from a voxel
- Design Matrix
- Regression parameters, Effect sizes
- Gaussian noise (temporal autocorrelation)
“Demeaning” and the GLM

• The mean value is uninteresting in an FMRI session

• There are two equivalent options:
  1. remove the mean from the data and don’t model it
  2. put a term into the model to account for the mean

In FSL we use option #1 for first-level analyses and #2 for higher-level analyses

A consequence is that the baseline condition in first-level analysis is **NOT** explicitly modelled (in FSL)
FMRI Modelling and Statistics

- An example experiment
- Multiple regression (GLM)
- \textit{T} and \textit{F} Contrasts
- Null hypothesis testing
- The residuals
- Thresholding: multiple comparison correction
t-contrasts

• A contrast of parameter estimates (COPE) is a linear combination of PEs:

\[
\begin{bmatrix} 1 & 0 \end{bmatrix}: \text{COPE} = 1 \times \hat{\beta}_1 + 0 \times \hat{\beta}_2 = \hat{\beta}_1
\]

\[
\begin{bmatrix} 1 & -1 \end{bmatrix}: \text{COPE} = 1 \times \hat{\beta}_1 + (-1) \times \hat{\beta}_2 = \hat{\beta}_1 - \hat{\beta}_2
\]

• Test null hypothesis that COPE=0

\[
t = \frac{\text{COPE}}{\text{std}(\text{COPE})}
\]
t-contrasts

\[ t = \frac{COPE}{\text{std}(COPE)} \]

Depends on

[1 0]

The Model, the Contrast, and the Residual Error
t-contrasts

\[ t = \frac{\text{COPE}_{\text{std}}}{\text{COPE}} \]

\[
\begin{bmatrix}
1 & 0
\end{bmatrix}
\]

The Model & the Contrast

and the Residual Error
**$t$-contrasts**

- [1 0] : EV1 only (i.e. Generation vs rest)
- [0 1] : EV2 only (i.e. Shadowing vs rest)

<table>
<thead>
<tr>
<th></th>
<th>Gen</th>
<th>Shad</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Generation</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>Shadowing</td>
<td>0</td>
</tr>
<tr>
<td>C3</td>
<td>Mean</td>
<td>1</td>
</tr>
<tr>
<td>C4</td>
<td>Shad &gt; Gen</td>
<td>-1</td>
</tr>
<tr>
<td>C5</td>
<td>Gen &gt; Shad</td>
<td>1</td>
</tr>
</tbody>
</table>
Contrast weight vector: \([1 \ 0]\)

Asks the question: Where do we need this regressor to model the data, i.e. what parts of the brain are used when seeing nouns and generating related verbs?
Contrast weight vector: $[1 \ 0]$

$$COPE = 1 \times 1.04 + 0 \times -0.10 = 1.04$$

$$COPE = \beta_1$$
\[
t = \frac{\text{COPE}}{\text{std(COPE)}}
\]
t-contrasts

- $[1 \ 0]$: EV1 only (i.e. Generation vs rest)
- $[0 \ 1]$: EV2 only (i.e. Shadowing vs rest)
- $[1 \ 1]$: EV1 + EV2 (Mean activation)
t-contrasts

Contrast weight vector: \([1 \ 1]\)

\[
\text{COPE} = 1 \times 1.10 + 1 \times 1.02 = 2.12
\]

Model

\[
\begin{bmatrix}
\beta_1 \\
\beta_2
\end{bmatrix}
\]
\[ t = \frac{\text{COPE}}{\text{std(COPE)}} \]

\[ \begin{bmatrix} 1.10 \\ 1.02 \end{bmatrix} \]
$t$-contrasts

- $[1 \ 0]$ : EV1 only (i.e. Generation vs rest)
- $[0 \ 1]$ : EV2 only (i.e. Shadowing vs rest)
- $[1 \ 1]$ : EV1 + EV2 (Mean activation)
- $[-1 \ 1]$ : EV2 - EV1 (More activated by Shadowing than Generation)
- $[1 \ -1]$ : EV1 - EV2 (More activated by Generation than Shadowing ($t$-tests are directional))
t-contrasts

Contrast weight vector: $[1 \ -1]$

COPE = $1 \times 1.04 - 1 \times -0.10 = 1.14$
t-contrasts

\[
\begin{bmatrix}
1.04 \\
-0.10
\end{bmatrix}
\]

\[
t = \frac{\text{COPE}}{\text{std(COPE)}}
\]
t-contrasts

Why $[1 -1]$ instead of $[1 0]$?

$[1 0]$

$\begin{bmatrix} 1.10 \\ 1.02 \end{bmatrix}$

$\beta_1$

$\beta_2$

$[1 -1]$

$\begin{bmatrix} 1 \end{bmatrix}$

$\begin{bmatrix} 0 \end{bmatrix}$

$\begin{bmatrix} 1.10 \\ 1.02 \end{bmatrix}$

$\begin{bmatrix} 1 \1 0 \end{bmatrix}$

$\begin{bmatrix} 1 \1 0 \end{bmatrix}$

$\begin{bmatrix} 1 \1 0 \end{bmatrix}$
F-contrasts

We have two conditions: Word Generation and Shadowing.

We want to know: Is there an activation to any condition?

First we ask: Is there activation to Generation?

\[
\begin{bmatrix}
1 & 0
\end{bmatrix}
\]
F-contrasts

We have two conditions: Word Generation and Shadowing

We want to know: Is there an activation to any condition?

Then we ask: Is there activation to Shadowing?

\[
\begin{bmatrix}
1 & 0 \\
0 & 1 \\
\end{bmatrix}
\]
F-contrasts

We have two conditions: Word Generation and Shadowing.

We want to know: Is there an activation to any condition?

Then we add the OR:

\[
\begin{bmatrix}
1 & 0 \\
0 & 1
\end{bmatrix}
\]
F-contrasts

We have two conditions: Word Generation and Shadowing

We want to know:
Is there an activation to any condition?

Is there an activation to any condition?
Is equivalent to:
Does any regressor explain the variance in the data?

Then we add the OR

\[
\begin{bmatrix}
1 & 0 \\
0 & 1
\end{bmatrix}
\]
F-contrasts
F-contrasts

Fit Model

Estimate Residuals

\( \text{SS}_E \)
F-contrasts

\[ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \]

Full Model

Fit Model

Estimate Residuals

\[ F = \frac{SS_R - SS_E}{SS_E} = \frac{\uparrow - \downarrow}{\downarrow} \]

Reduced Model

\[ \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \]
F-contrasts

\[ F = \frac{SS_R - SS_E}{SS_E} \]
F-contrasts

- Two conditions: A, B
- Is any condition significant?
- Set of COPEs form an F-contrast
- Or: “Is there a significant amount of power in the data explained by the combination of the COPEs in the F-contrast?”
- F-contrast is F-distributed
The GLM is used to summarise data in a few parameters that are pertinent to the experiment.

GLM predicts how BOLD activity might change as a result of the experiment.

We can test for significant effects by using t or f contrasts on the GLM parameters.

That's all folks