Dynamic causal modelling of visual imagery and perception

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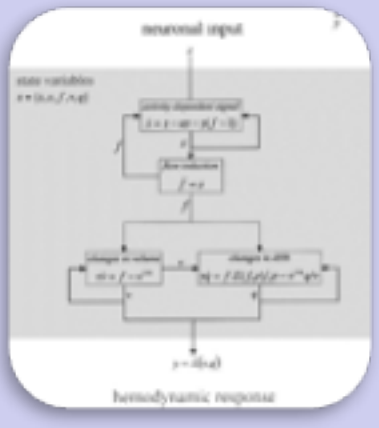
SPM course May 24th 2019
UCL, London, United Kingdom

DCM Framework

Experimental Stimulus (u)

Neural Model

Observation Model



Observations (y)

How brain activity **z** changes over time

$$z \doteq f(z,u,\theta^n)$$

What we would see in the scanner, y, given the neural model?

$$y = g(z, \theta^h)$$

Stimulus from Buchel and Friston, 1997
Figure 3 from Friston et al., Neuroimage, 2003
Brain by Dierk Schaefer, Flickr, CC 2.0

The Neural model

$$\dot{z} = \begin{bmatrix} \dot{z}_1 \\ \vdots \\ \dot{z}_n \end{bmatrix} = f(z, u, \theta)$$

Deterministic DCM for fMRI

Task

$$\dot{z} = (A + \sum_{j=1}^{m} u_j B^j)z + Cu$$

(*Taylor approximation)*

Friston et al., Neuroimage, 2003

DCM for CSD

Resting State

$$\dot{z} = Az + v$$

Friston et al., Neuroimage, 2014

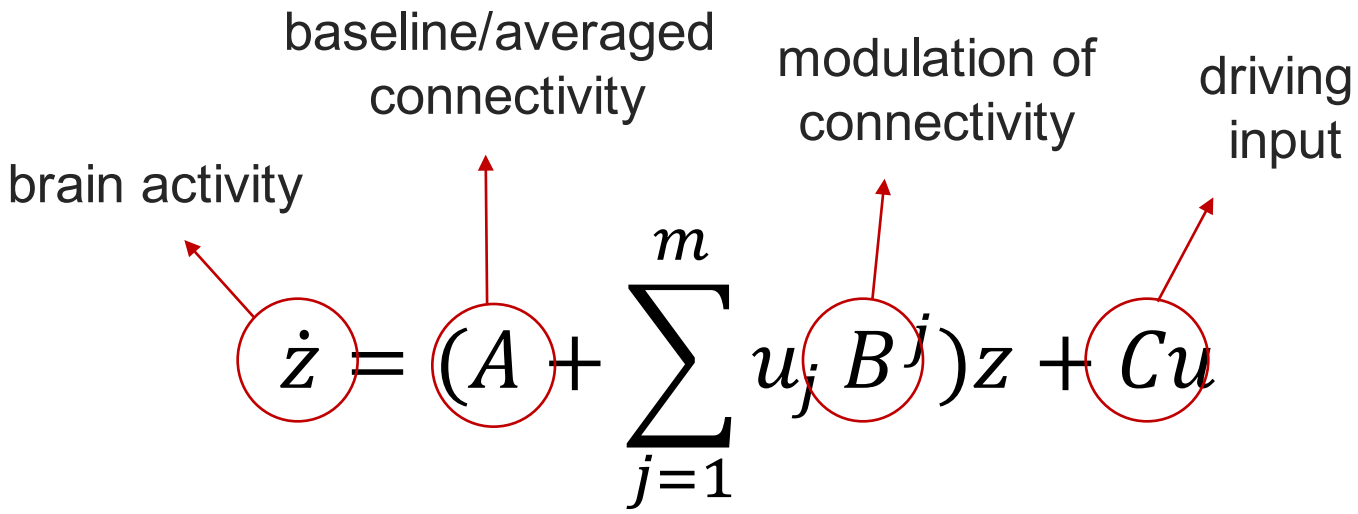
Canonical Microcircuit

Coming soon

Friston et al., Neuroimage, 2017

The Neural model

"How does brain activity, z, change over time?"

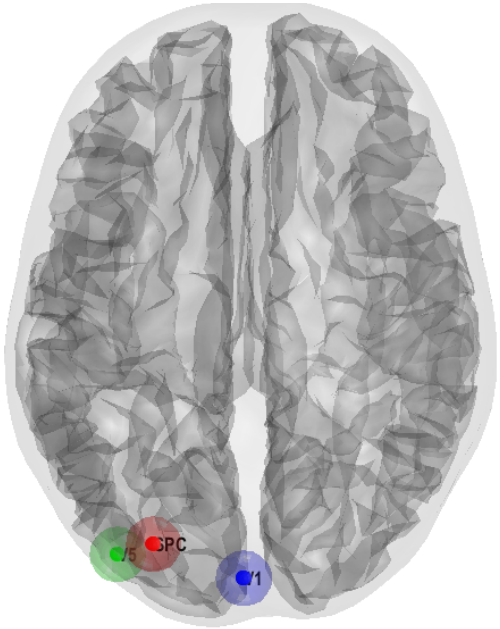


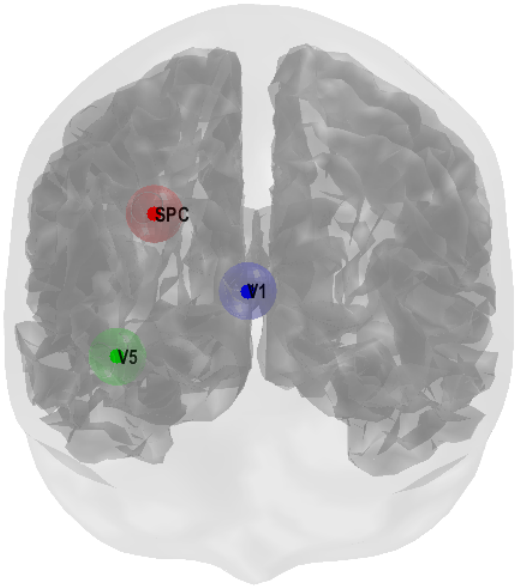
Friston et al. 2003

The Neural Model

"How does brain activity, z, change over time?"

- Subjects viewed moving dots during fMRI
- On some trials, subjects were instructed to pay attention to the speed of the dots' motion
- Question: How does attention to motion change the strength of the connections between V1, V5 and Superior Parietal Cortex?





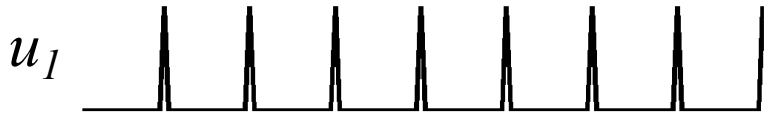
V1

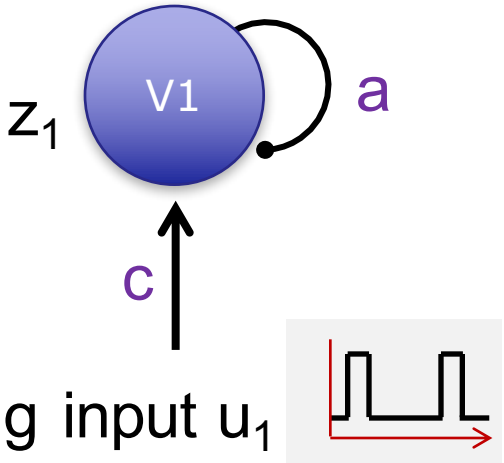
V5

SPC

The Neural Model

"How does brain activity, z, change over time?"





$$\dot{z}_1 = az + cu_1$$

Inhibitory self-connection (Hz). Rate constant: controls rate of decay in region 1. More negative = faster decay.

The Neural Model

"How does brain activity, z, change over time?"

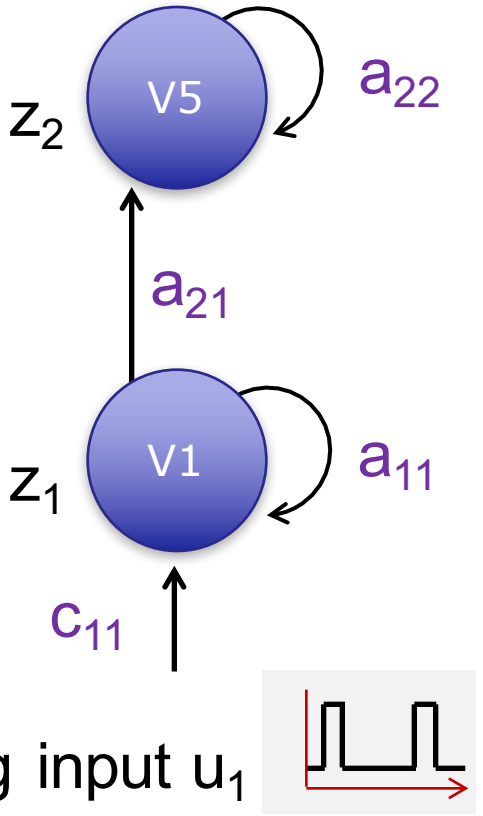
Change of activity in V1:

$$\dot{z}_1 = a_{11}z_1 + c_{11}u_1$$

Change of activity in V5:

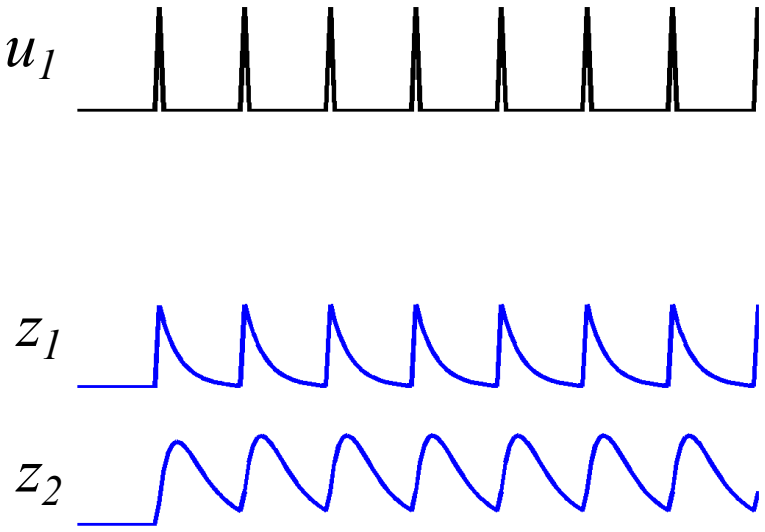
$$\dot{z}_2 = a_{22}z_2 + a_{21}z_1$$

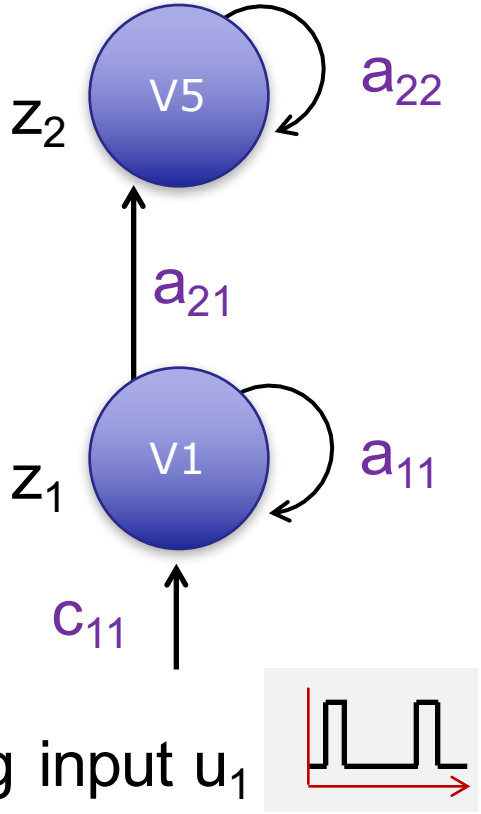
Self decay V1 input



The Neural Model

"How does brain activity, z, change over time?"





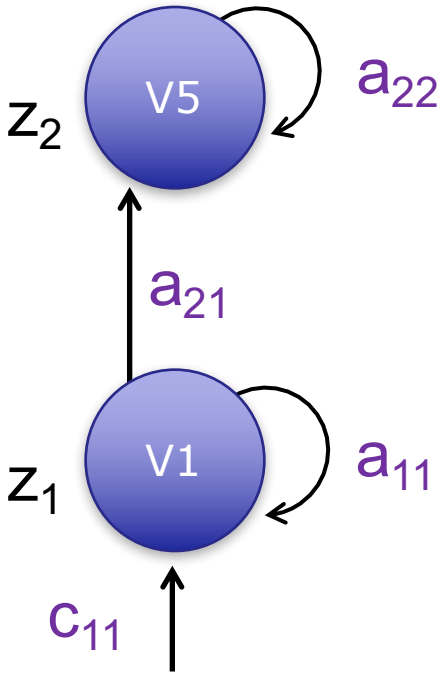
The Neural Model

"How does brain activity, z, change over time?"

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c_{11} \\ 0 \end{bmatrix} u_1$$

Columns are outgoing connections
Rows are incoming connections

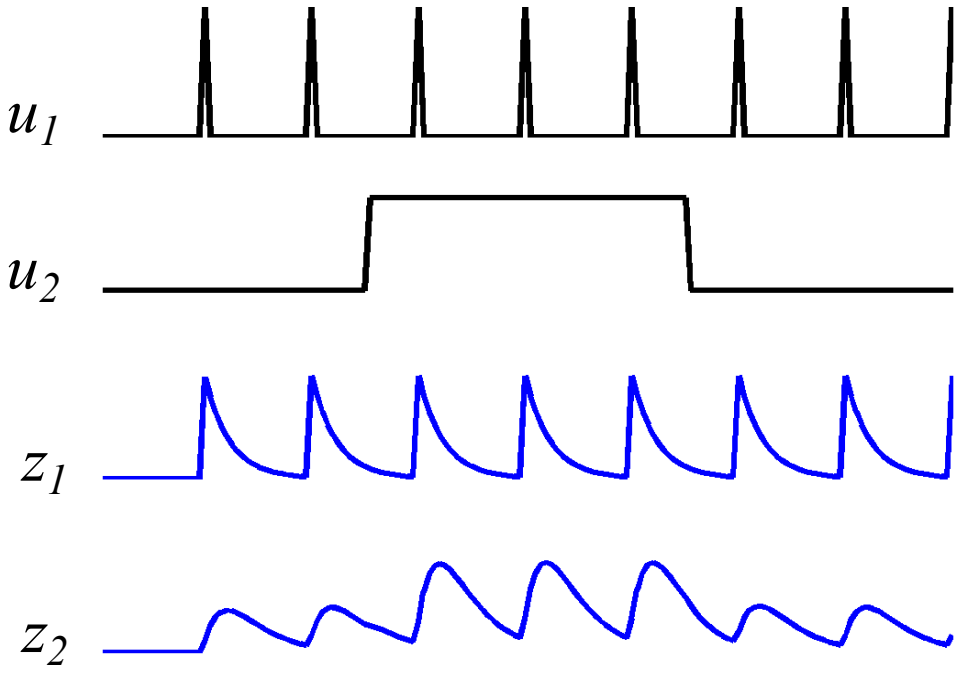
$$\dot{z} = Az + Cu_1$$

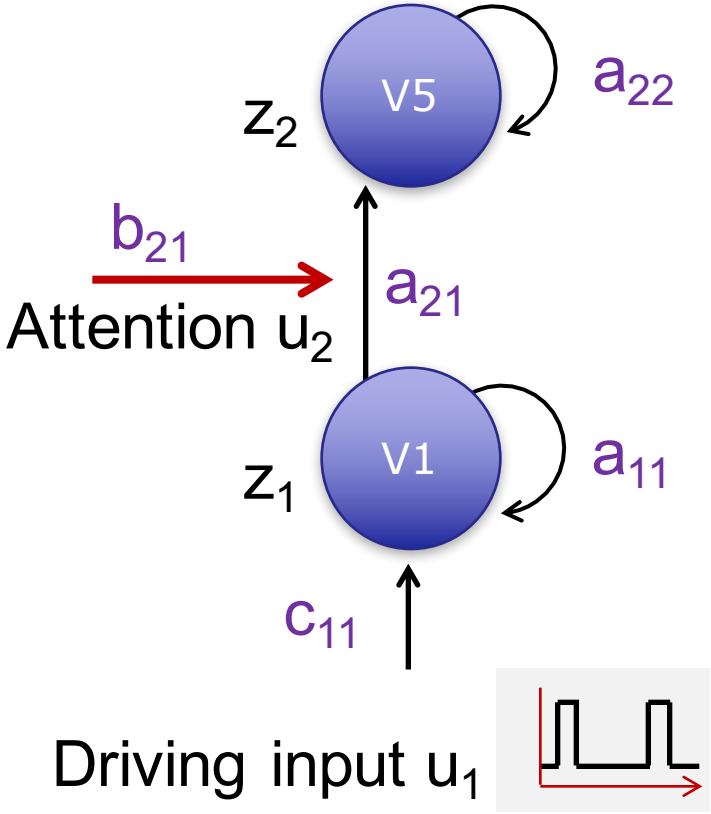


Driving input u_1

The Neural Model

"How does brain activity, z, change over time?"





The Neural Model

"How does brain activity, z, change over time?"

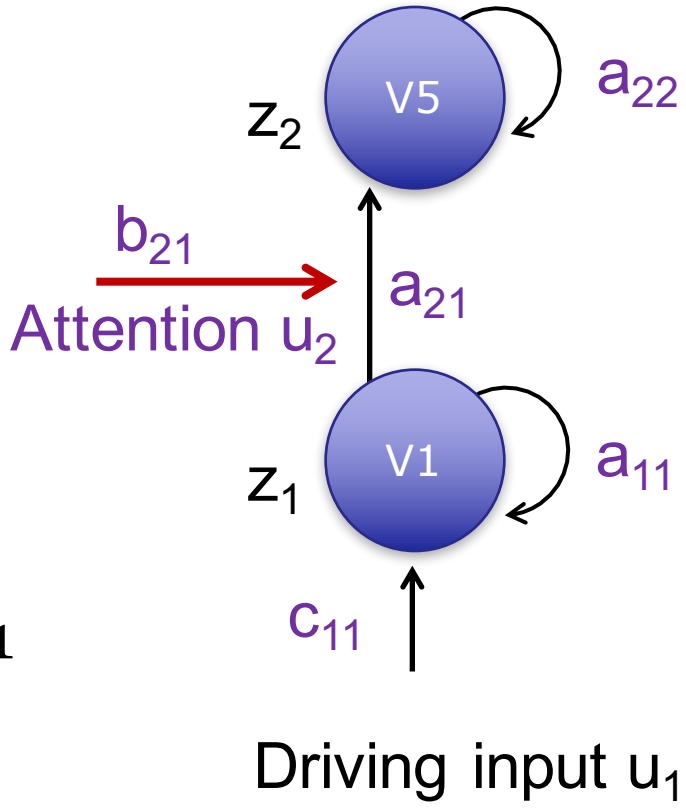
Change of activity in V1:

$$\dot{z}_1 = a_{11} z_1 + c_{11} u_1$$

Change of activity in V5:

$$\dot{z}_2 = a_{22} z_2 + a_{21} z_1 + (b_{21} u_2) z_1$$

Self decay V1 input Modulatory input



The Neural Model

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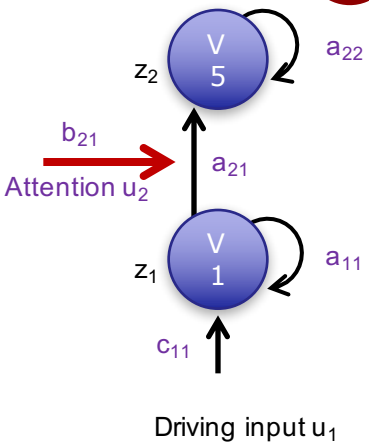


For m experimental inputs:

$$\dot{z} = (A + \sum_{j=1}^{m} u_j B^j)z + Cu$$

Columns: outgoing connections
Rows: incoming connections

A: Structure

B: Modulatory Input

C: Driving Input

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \end{bmatrix} = \left(\begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix} + u_2 \begin{bmatrix} 0 & 0 \\ b_{21} & 0 \end{bmatrix} \right) \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} + \begin{bmatrix} c_{11} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

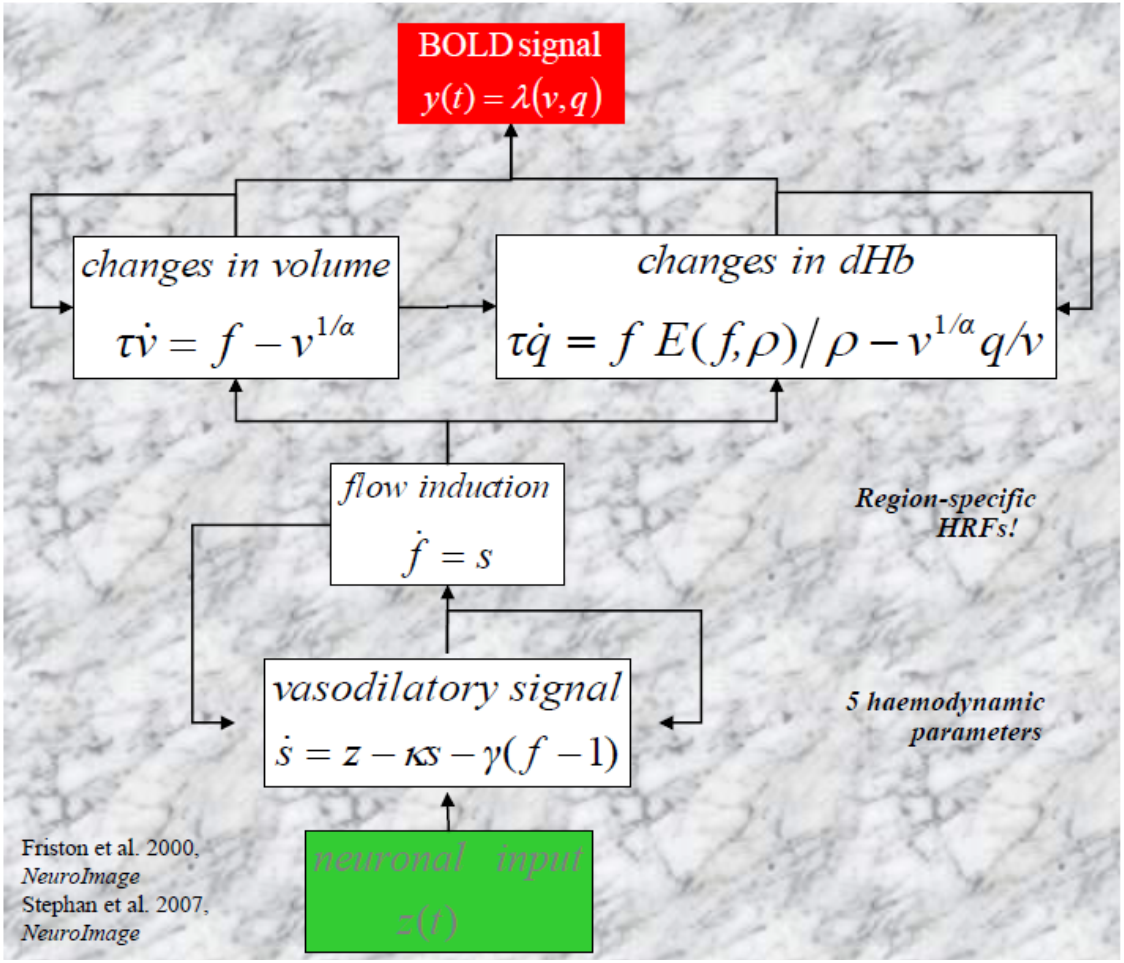
Change in activity per region

External input 2 (attention)

Current activity per region

All external input

The Haemodynamic Model



DCM Framework

Experimental Stimulus (u)

Neural Model

Observation Model

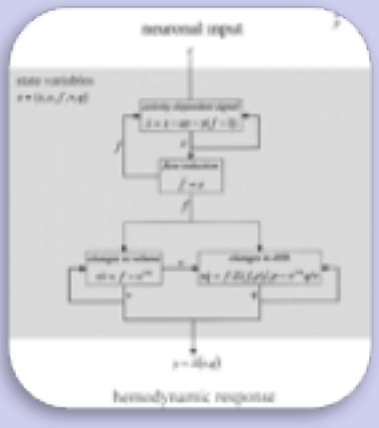


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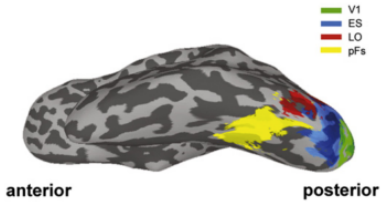
Figure 3 from Friston et al., Neuroimage, 2003
Brain by Dierk Schaefer, Flickr, CC 2.0

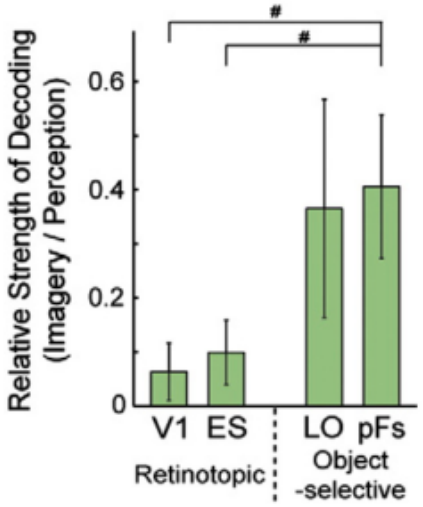
Distinct Top-Down and Bottom-Up Brain Connectivity during Visual Perception and Imagery

Nadine Dijkstra, Peter Zeidman, Sasha Ondobaka, Marcel van Gerven & Karl Friston (2017) *Scientific Reports*

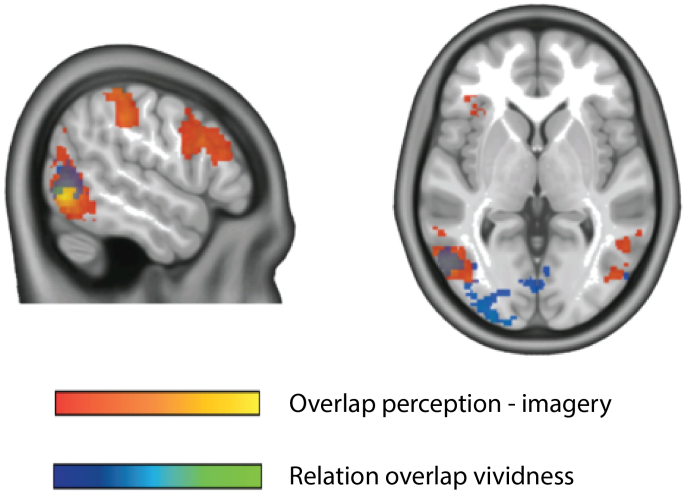
Using DCM to investigate directional connectivity during visual perception and imagery

Background: overlap





Lee et al. (2012)
Neuroimage

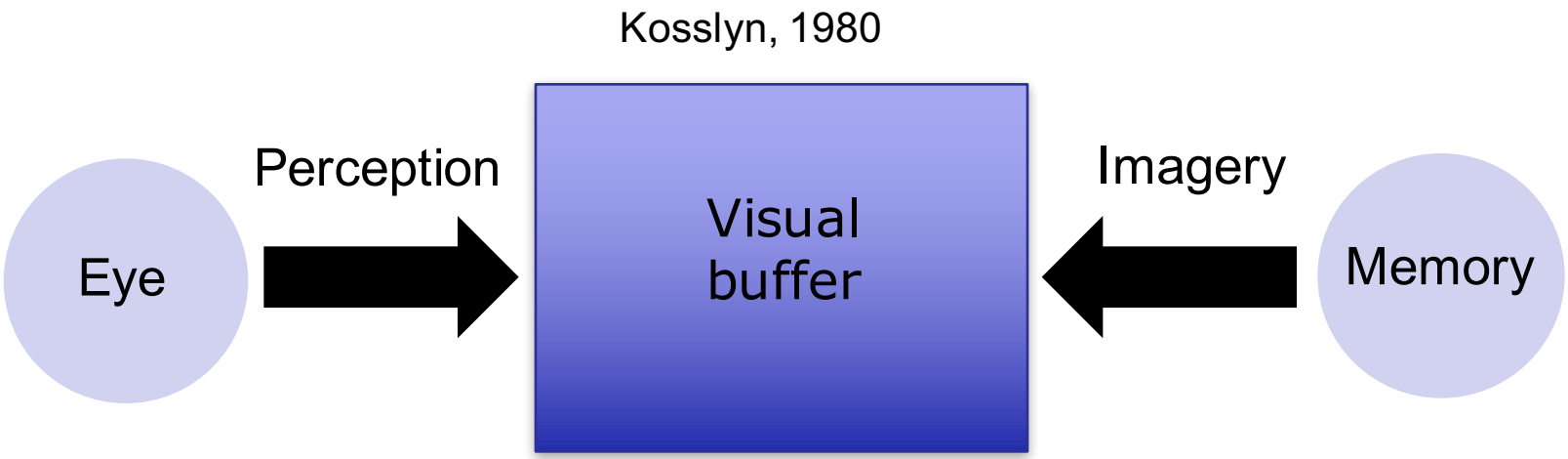


Dijkstra, Bosch & van Gerven (2017)
Journal of Neuroscience

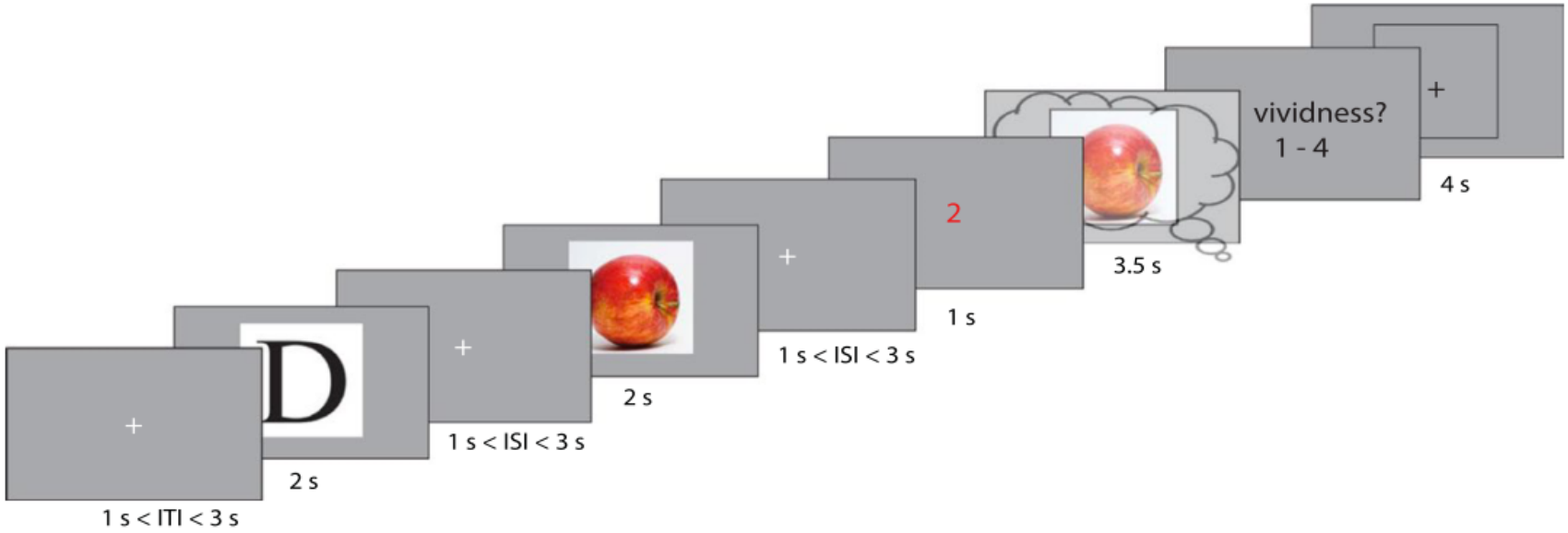
Large overlap in neural representations of perceived and imagined stimuli
Dijkstra, N. et al., (2019) *Trends in Cognitive Sciences*

Dijkstra, N., Zeidman, P., Ondobaka, S., van Gerven, M., & Friston, K. (2017) *Scientific Reports*

Background: two mechanisms



Experimental design

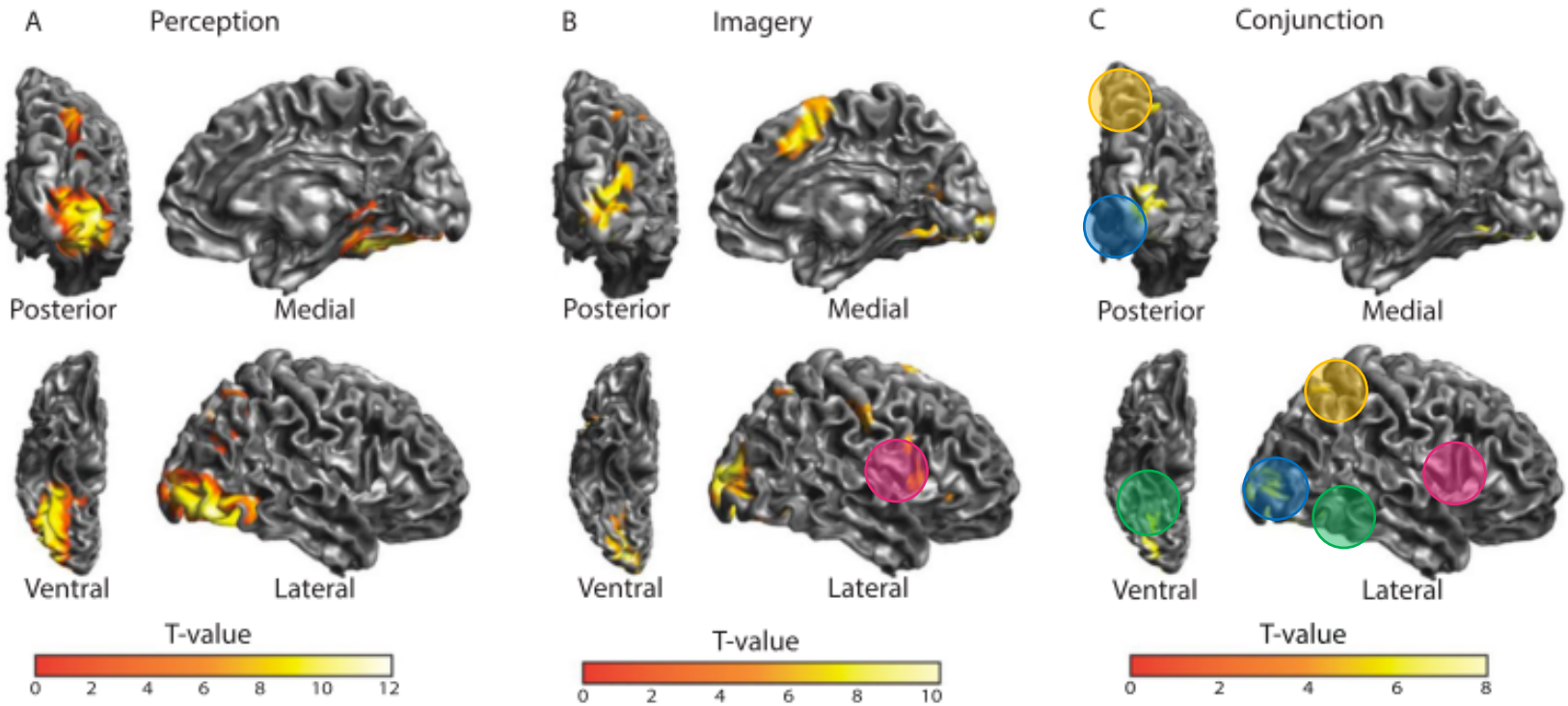


Perception

Imagery

Dijkstra, N., Bosch, S., & van Gerven, M. (2017) *Journal of Neuroscience*
Dijkstra, N., Zeidman, P., Ondobaka, S., van Gerven, M., & Friston, K. (2017) *Scientific Reports*

Selection of regions



Dijkstra, N., Zeidman, P., Ondobaka, S., van Gerven, M., & Friston, K. (2017) *Scientific Reports*

Time series extraction

- 1 time series per region
  - Mask (e.g. anatomical mask)
  - Find peak relevant contrast
    - Sphere (x mm)
    - Box (x mm by y mm by z mm)
    - Cluster (all voxels exceeding threshold)

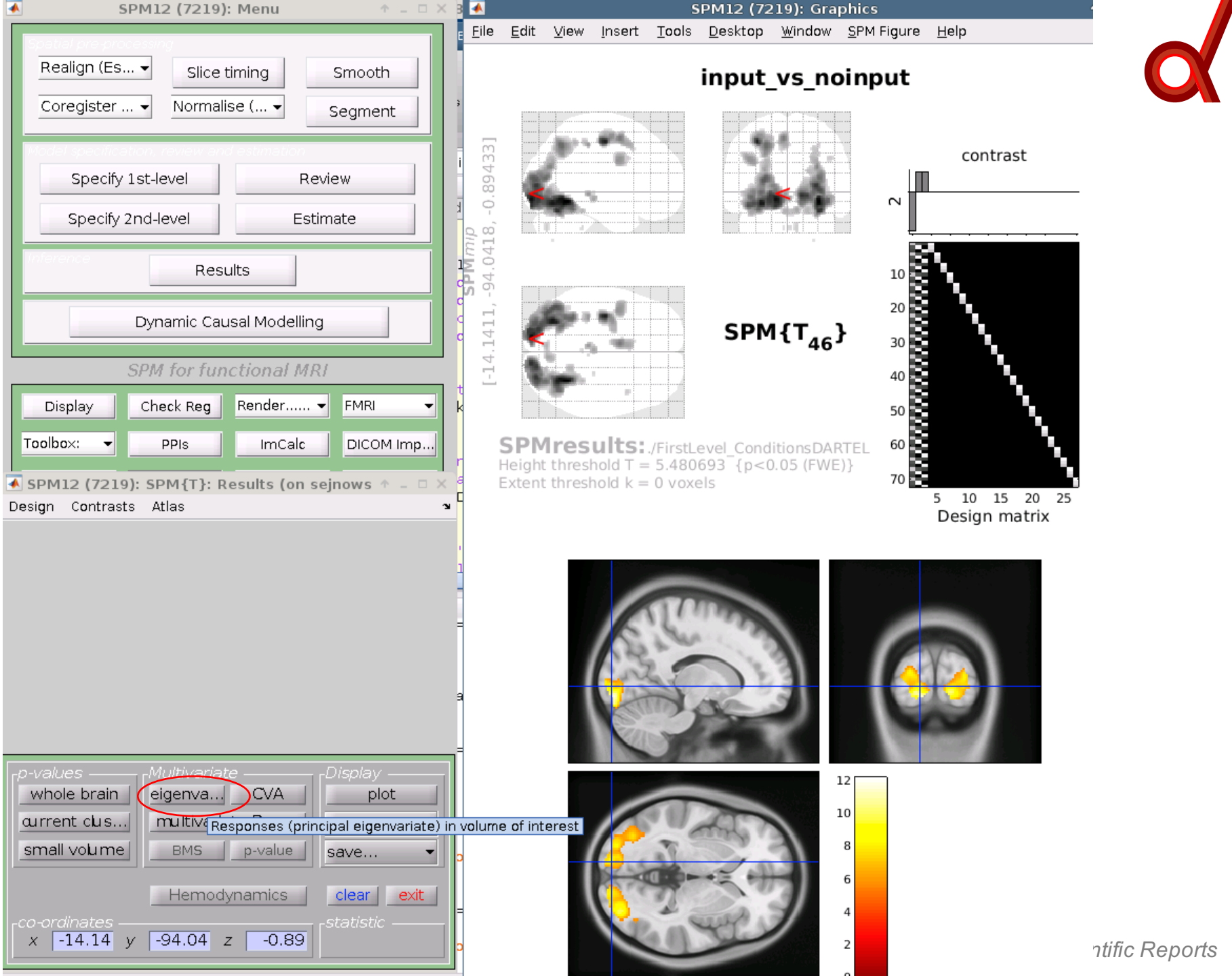
Time series extraction

- Regress out unrelated variance (e.g. head movement)
  - Adjust based on effect of interest
  - F-contrast, e.g.

$$\left(\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\right)$$

- Take 1st principal component, i.e. eigenvariate

Dijkstra, N., Zeidman, P., Ondobaka, S., van Gerven, M., & Friston, K. (2017) *Scientific Reports*


SPM12 (7219): Menu
Realign (Es...
Slice timing
Smooth
Coregister ...
Normalise (...
Segment
Specify 1st-level
Review
Specify 2nd-level
Estimate
Results
Dynamic Causal Modelling
SPM for functional MRI
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FMRI
Toolbox:
PPIs
ImCalc
DICOM Imp...
SPM12 (7219): SPM{T}: Results (on sejnows
Design
Contrasts
Atlas
p-values
whole brain
current clus...
small volume
Multivariate
eigenva...
CVA
BMS
p-value
Display
plot
save...
Hemodynamics
clear
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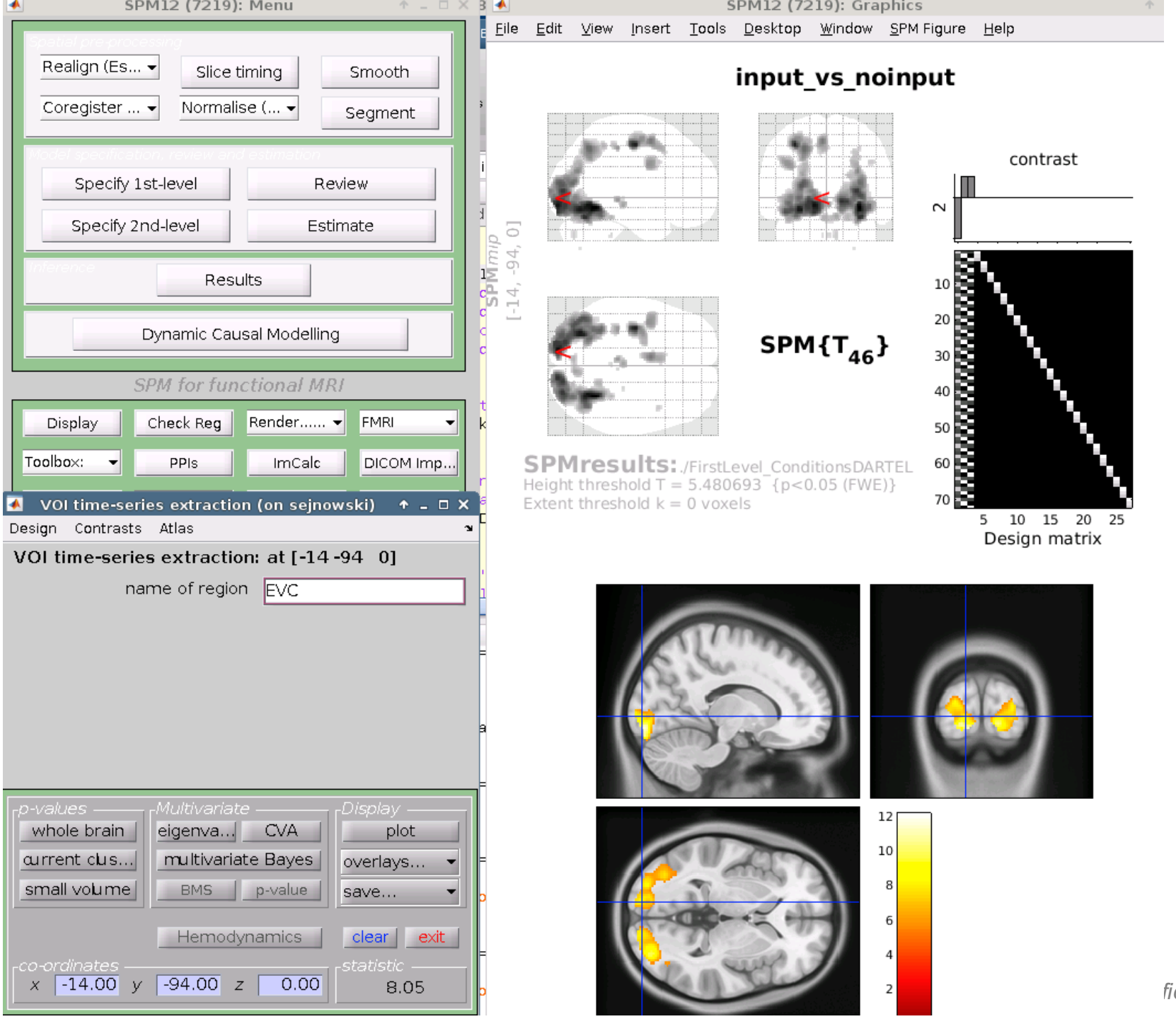
co-ordinates
x -14.14 y -94.04 z -0.89
statistic
Responses (principal eigenvariate) in volume of interest
SPM12 (7219): Graphics
File Edit View Insert Tools Desktop Window SPM Figure Help
input_vs_noinput
[-14.1411, -94.0418, -0.894333]
SPM{T46}
SPMresults: ./FirstLevel_ConditionsDARTEL
Height threshold T = 5.480693 {p<0.05 (FWE)}
Extent threshold k = 0 voxels
contrast
Design matrix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VOI time-series extraction (on sejnowski)
Design
Contrasts
Atlas
VOI time-series extraction: at [-14 -94 0]
name of region
EVC
p-values
whole brain
current clus...
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Multivariate
eigenva...
CVA
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Display
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overlays...
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Hemodynamics
clear
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co-ordinates
x -14.00 y -94.00 z 0.00
statistic
8.05
SPM12 (7219): Graphics
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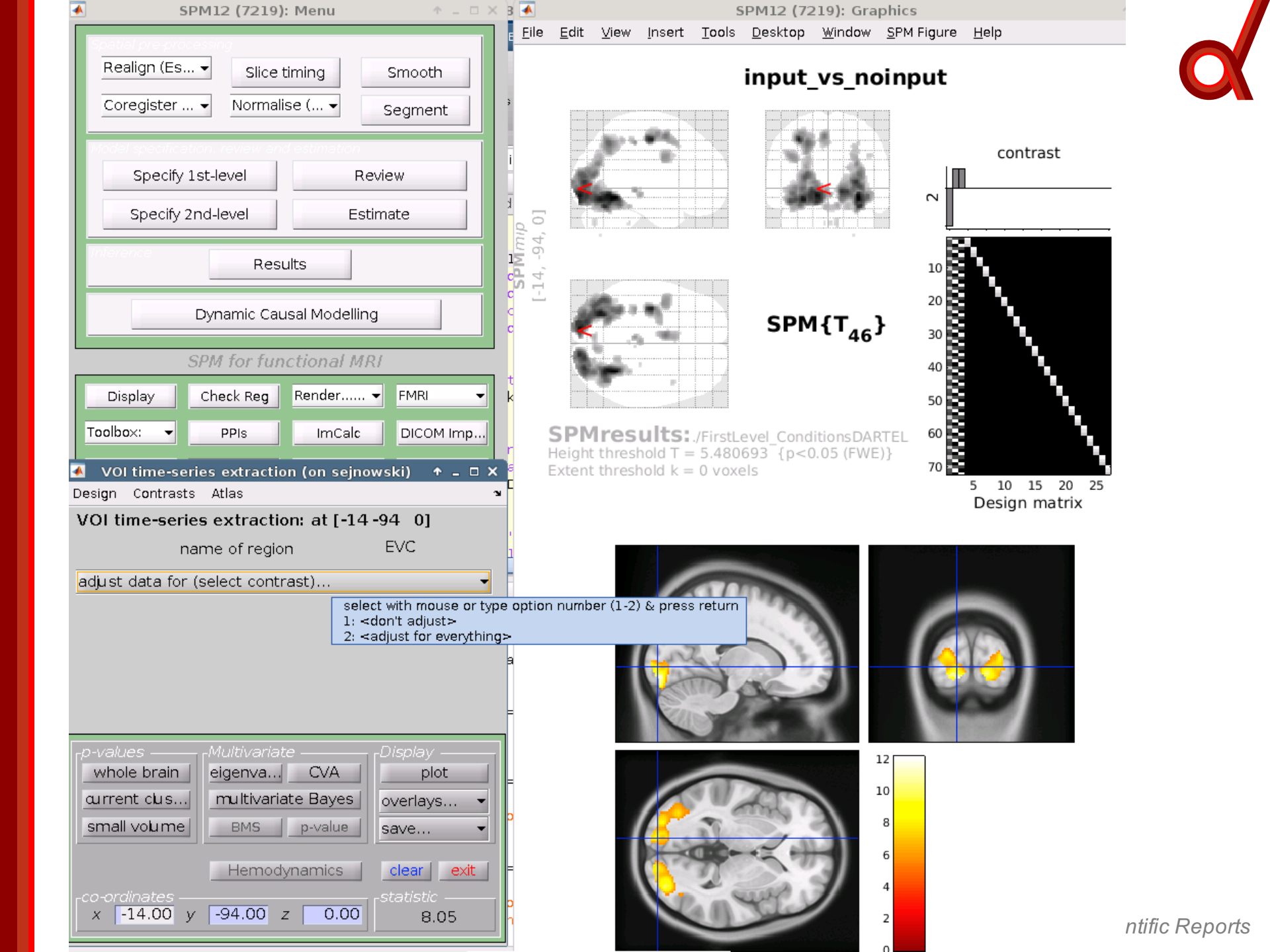
SPM Figure
Help
input_vs_noinput
SPM mip
[-14, -94, 0]
SPM{T46}
contrast
2
Design matrix
SPMresults: ./FirstLevel_ConditionsDARTEL
Height threshold T = 5.480693 {p<0.05 (FWE)}
Extent threshold k = 0 voxels


SPM12 (7219): Menu
Spatial pre-processing
Realign (Es...
Slice timing
Smooth
Coregister ...
Normalise (...
Segment
Model specification, review and estimation
Specify 1st-level
Review
Specify 2nd-level
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VOI time-series extraction (on sejnowski)
Design
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Atlas
VOI time-series extraction: at [-14 -94 0]
name of region
EVC
adjust data for (select contrast)...
select with mouse or type option number (1-2) & press return
1: <don't adjust>
2: <adjust for everything>
p-values
whole brain
current clus...
small volume
Multivariate
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CVA
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input_vs_noinput
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SPM{T46}
SPMresults: ./FirstLevel_ConditionsDARTEL
Height threshold T = 5.480693 {p<0.05 (FWE)}
Extent threshold k = 0 voxels
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70
5
10
15
20
25
Design matrix
12
10
8
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SPM12 (7219): Menu

Spatial pre-processing
Realign (Es... | Slice timing | Smooth
Coregister ... | Normalise (... | Segment

Model specification, review and estimation
Specify 1st-level | Review
Specify 2nd-level | Estimate

Inference
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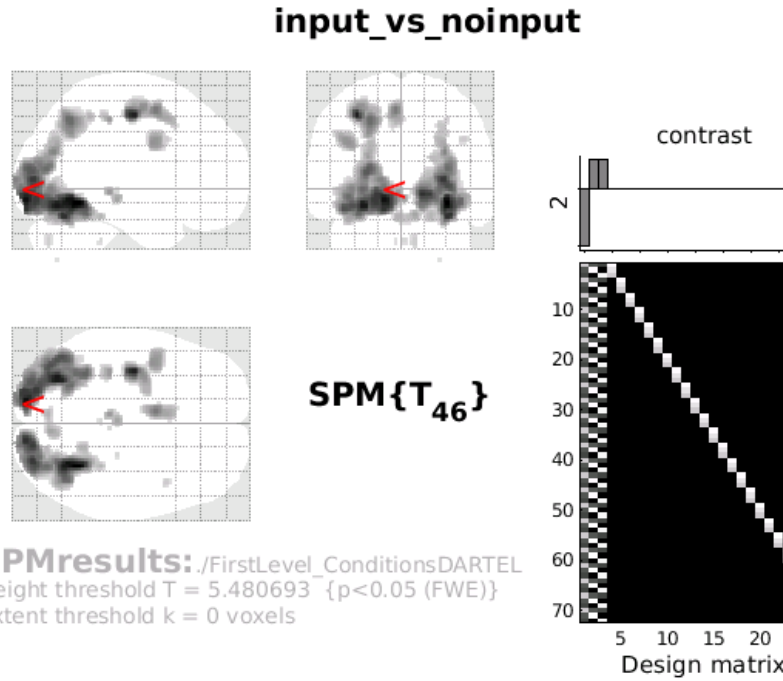
Dynamic Causal Modelling

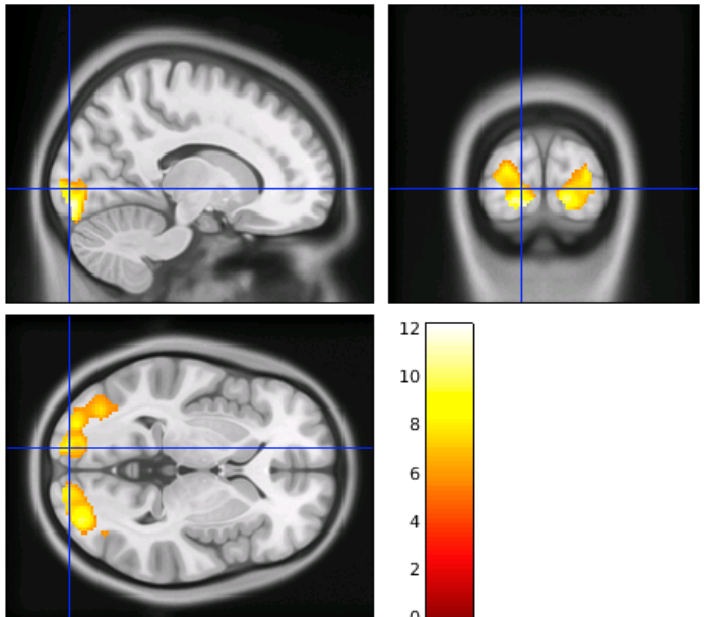
SPM for functional MRI
Display | Check Reg | Render..... | FMRI
Toolbox: | PPIs | ImCalc | DICOM Imp...

VOI time-series extraction (on sejnowski)
Design Contrasts Atlas
VOI time-series extraction: at [-14 -94 0]
name of region EVC
<don't adjust>
VOI definition... sph... box clu... mask
sphere
select with mouse or use kbd: s/b/c/m

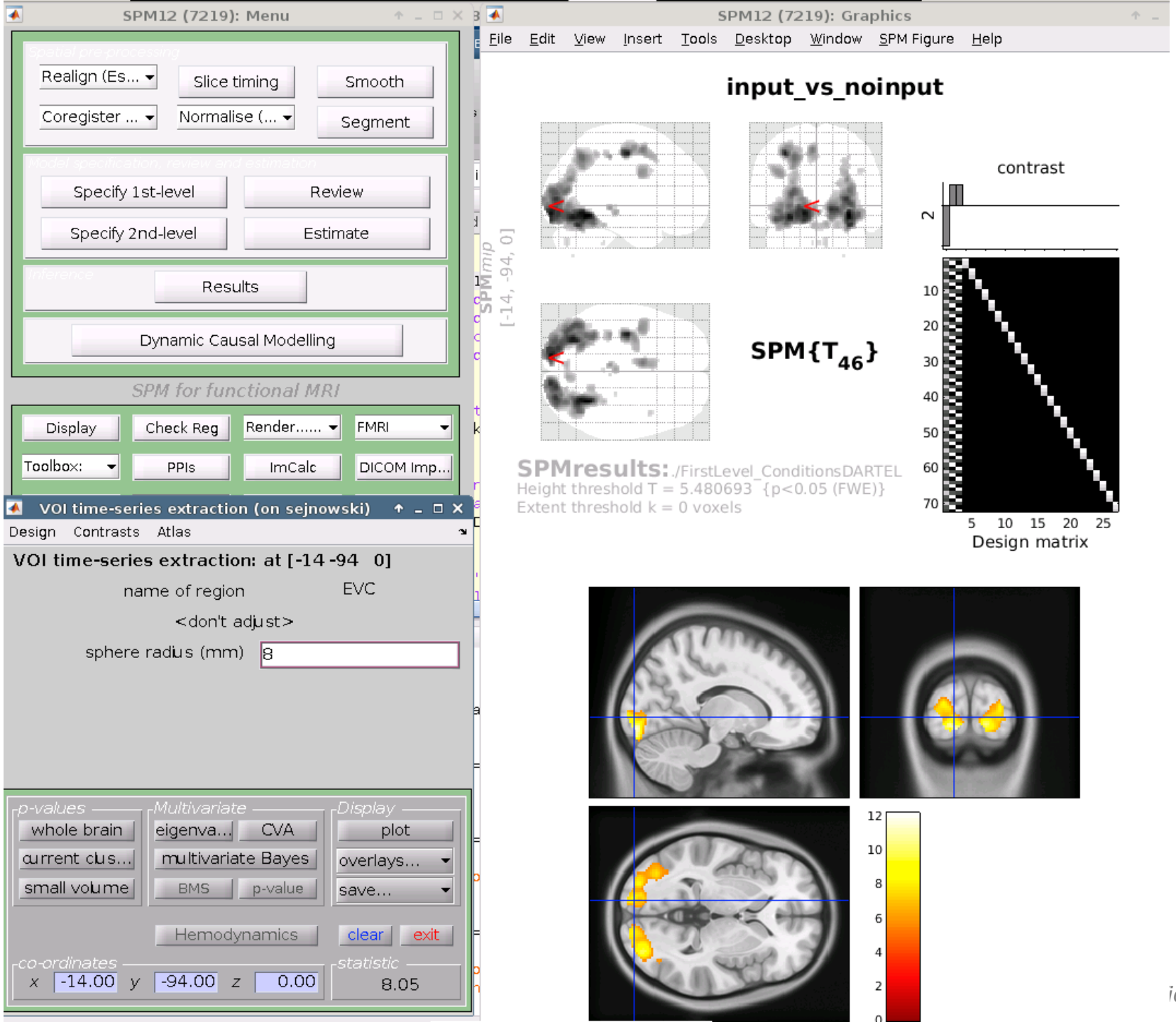
p-values: whole brain | current clus... | small volume
Multivariate: eigenva... | CVA | multivariate Bayes | BMS | p-value
Display: plot | overlays... | save...
Hemodynamics | clear | exit
co-ordinates: x -14.00 y -94.00 z 0.00
statistic: 8.05

SPM12 (7219): Graphics
File Edit View Insert Tools Desktop Window SPM Figure Help





Reports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Design matrix
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Realign (Es... | Slice timing | Smooth

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Model specification, review and estimation

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Toolbox: | PPIs | ImCalc | DICOM Imp...

SPM12 (7219): SPM{T}: Results (on sejnows

Design | Contrasts | Atlas

VOI time-series extraction: at [-14 -94 0]

name of region EVC

<don't adjust>

sphere radius (mm) 8

p-values: whole brain | current clus... | small volume

Multivariate: eigenva... | CVA | multivariate Bayes | BMS | p-value

Display: plot | overlays... | save...

Hemodynamics | clear | exit

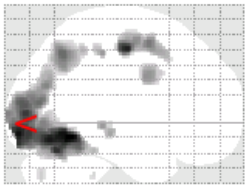
co-ordinates: x -14.00 y -94.00 z 0.00

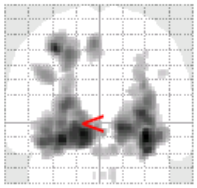
statistic: 8.05

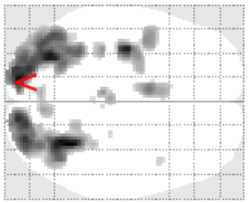
SPM12 (7219): Graphics

File | Edit | View | Insert | Tools | Desktop | Window | SPM Figure | Help

input_vs_noinput

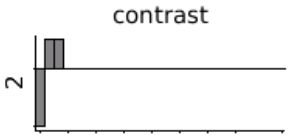


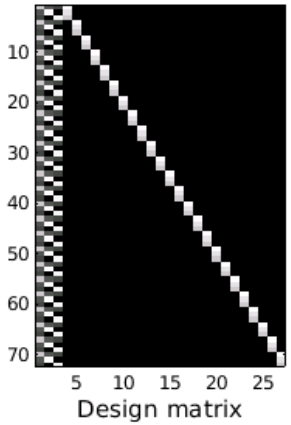




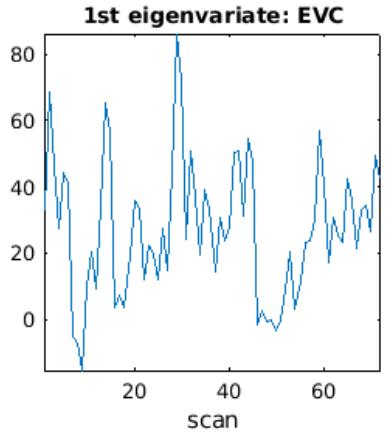
SPM mip [-14, -94, 0]

SPM{T_{46}}



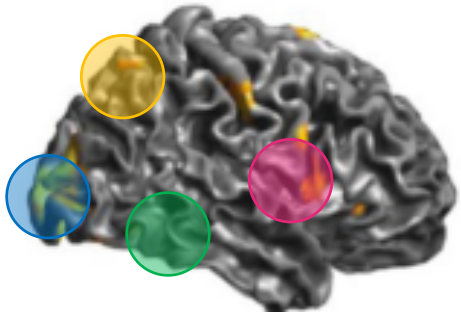


SPMresults: ./FirstLevel_ConditionsDARTEL
Height threshold T = 5.480693 {p<0.05 (FWE)}
Extent threshold k = 0 voxels



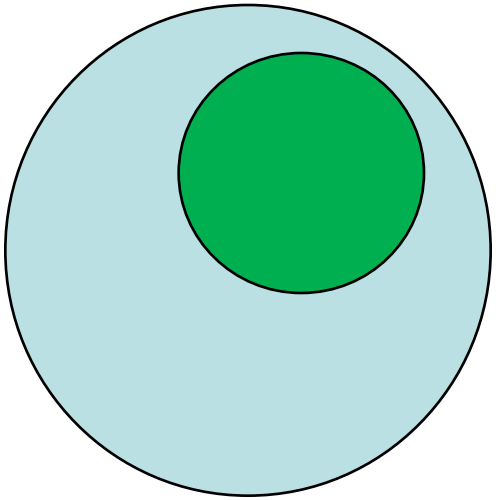
211 voxels in VOI at [-14 -94 0]
Variance: 86.69%

Time series extraction



- 8 mm sphere per subject within 16 mm sphere of group effect

check: https://en.wikibooks.org/wiki/SPM/Timeseries_extraction



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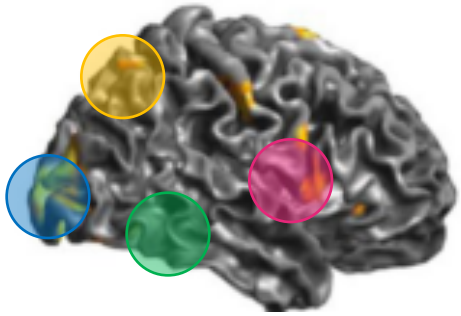
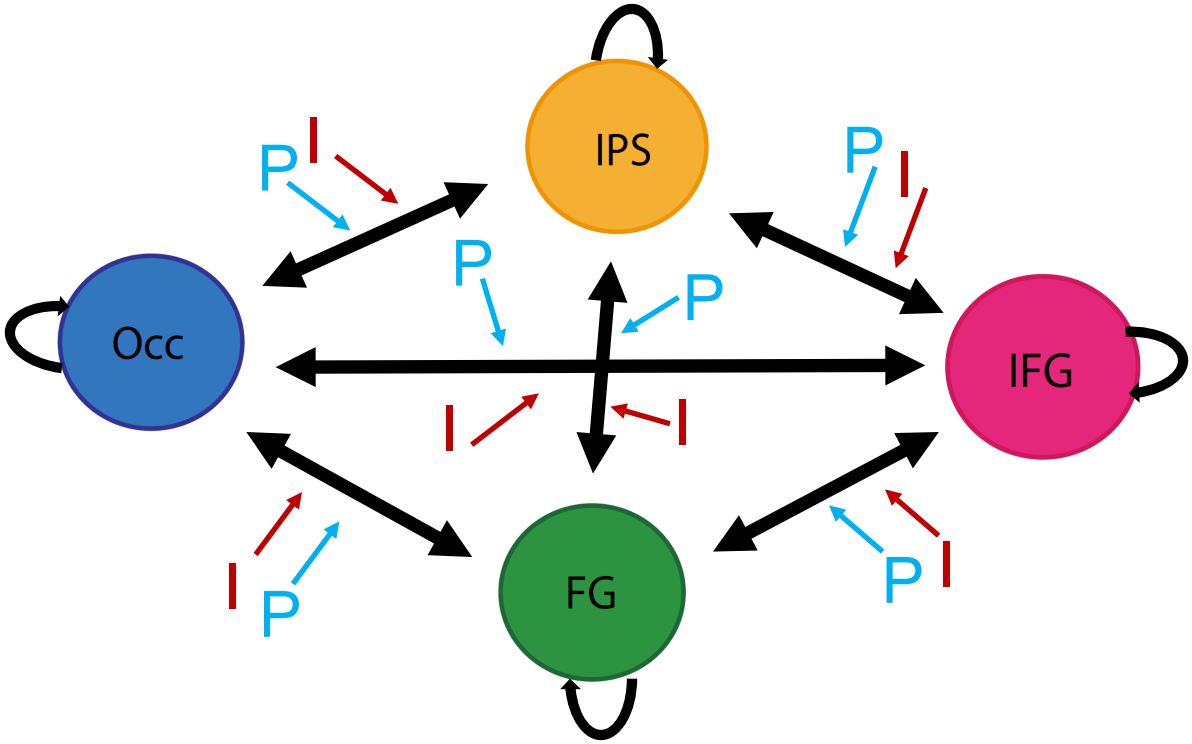
Definition of model



- Fully connected
- Bayesian Model Reduction

  Parametric Empirical Bayes



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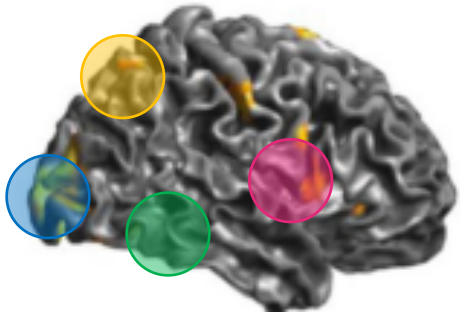
Definition of model



$$A = \left(\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}\right)$$

Perception

$$B(:,:,1) = \left(\begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{bmatrix}\right)$$

Imagery

$$B(:,:,2) = \left(\begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{bmatrix}\right)$$

Vividness

$$B(:,:,3) = \left(\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{bmatrix}\right)$$

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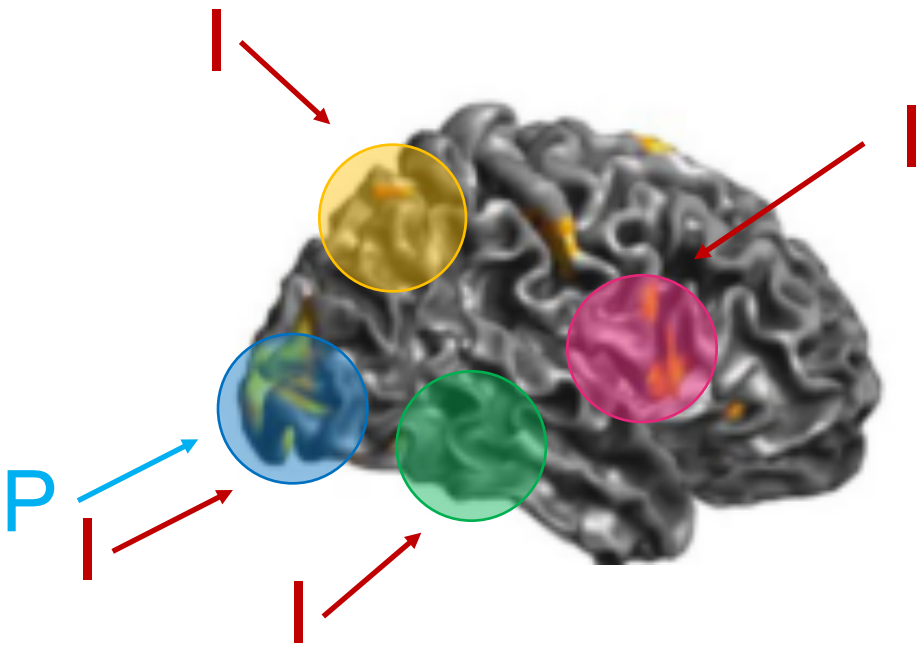
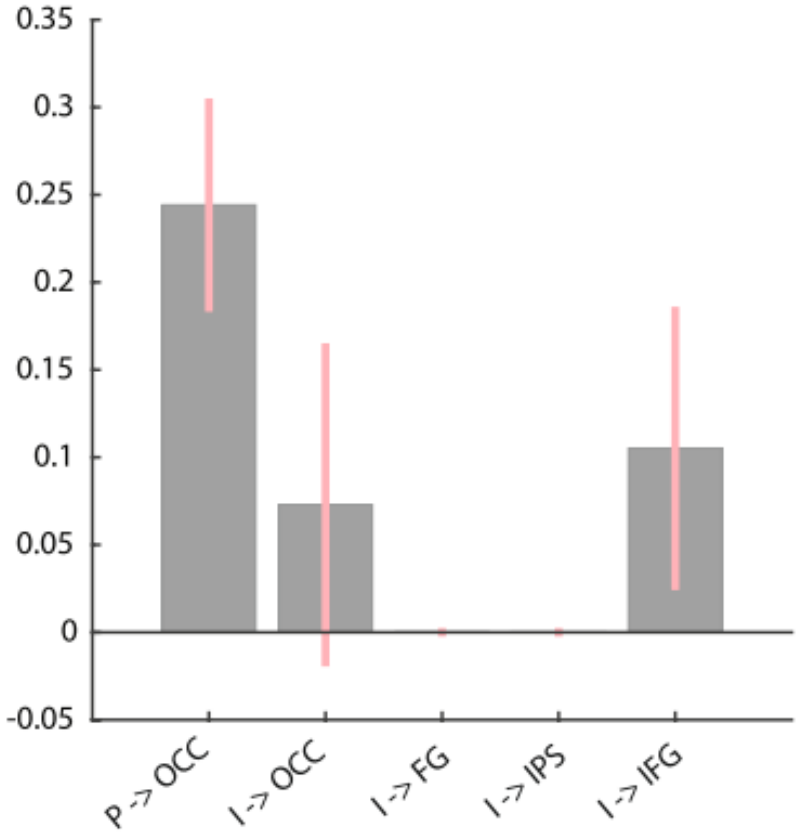
Definition of model: driving input





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Definition of model: driving input

Perception

$$C(:,:,1) = \left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \right)$$

Imagery

$$C(:,:,2) = \left(\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \right)$$

$$\dot{z} = (A + \sum_{j=1}^{m} u_j B^j)z + Cu$$

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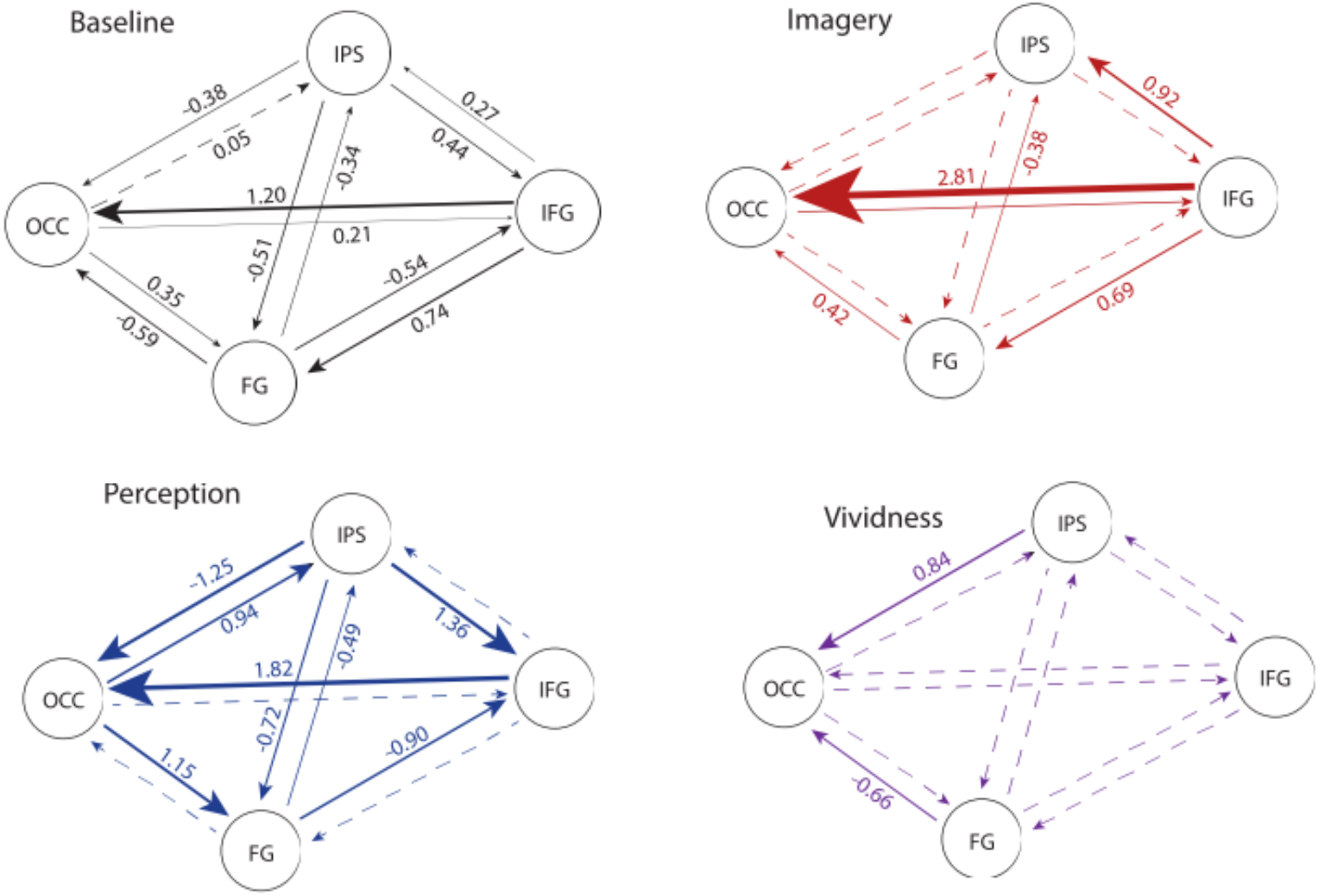
Results



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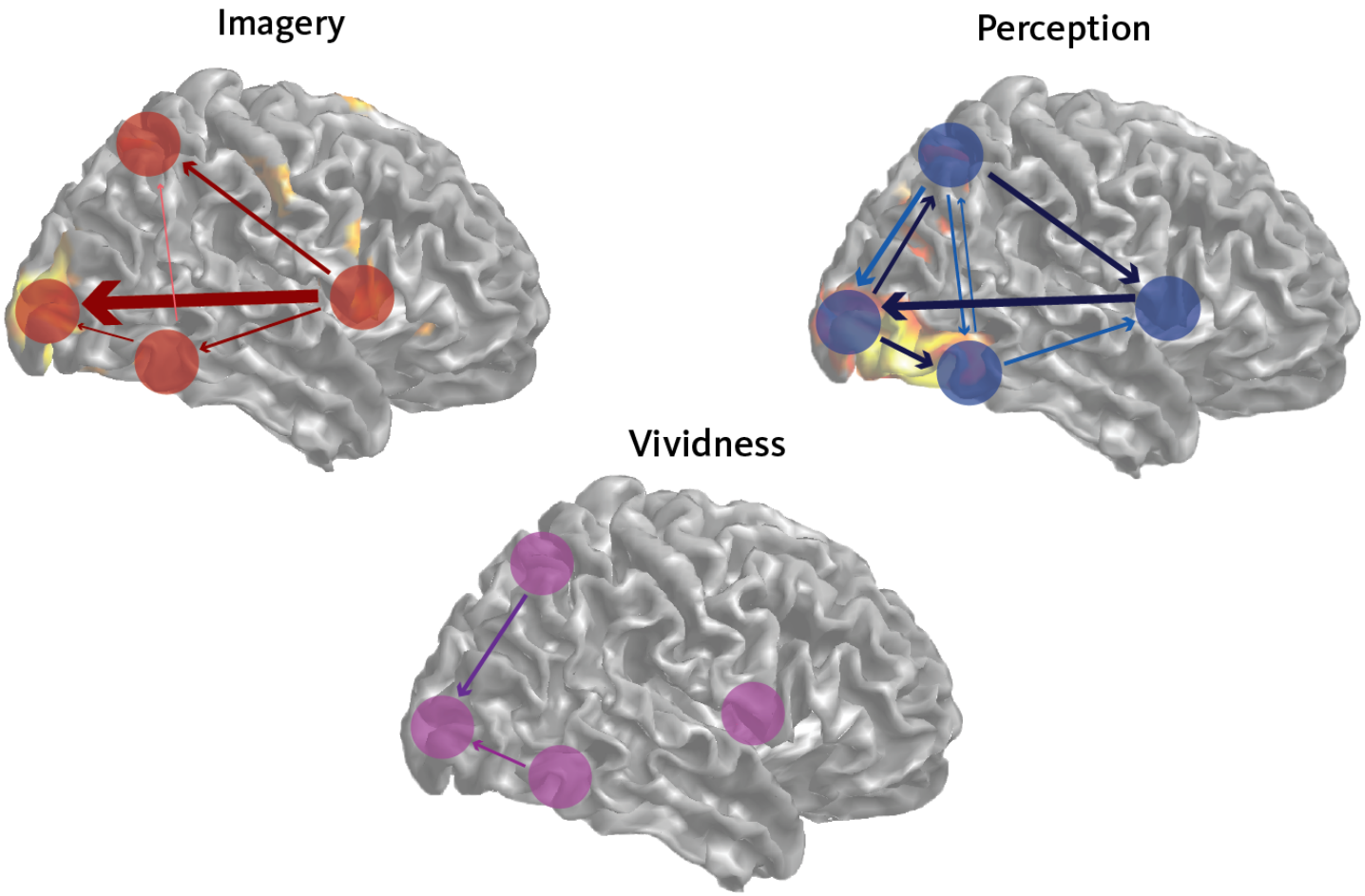
Results



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Conclusions

- Perception and imagery are both associated with increases in top-down coupling
  - Connectivity from IFG to OCC is present in both
    - (2 x stronger in imagery)
    - increase of visual activity relevant to current task
- Bottom-up coupling is only increased during perception
- Vividness is specifically associated with increases in top-down coupling to OCC

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Erasmus+

Thank you

Peter Zeidman

Sasha Ondobaka

Karl Friston