First level fMRI data analysis

Turku PET Centre Brain Imaging Course 2026

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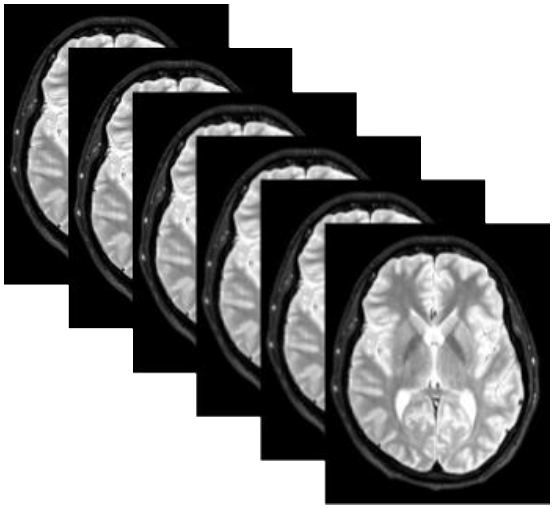
Outline

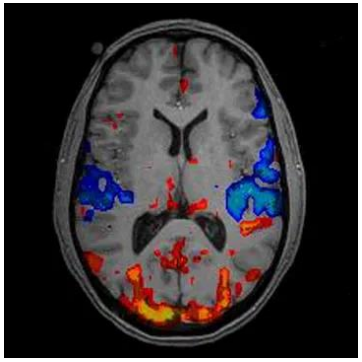
- What is 1st level analysis?
- Statistical models
- Contrasts
- Examples for illustration
  - –Operation in SPM12
  - –Reading the results, e.g., the contrasts

What is 1st level analysis?

- fMRI data analysis has two levels: 1st (within-subject) and 2nd (group-level).



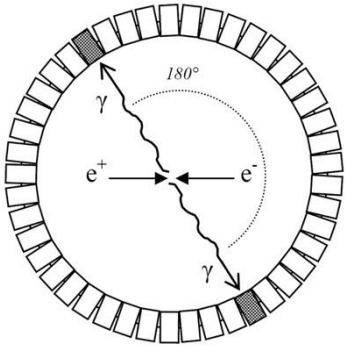
One subject's raw T2* data

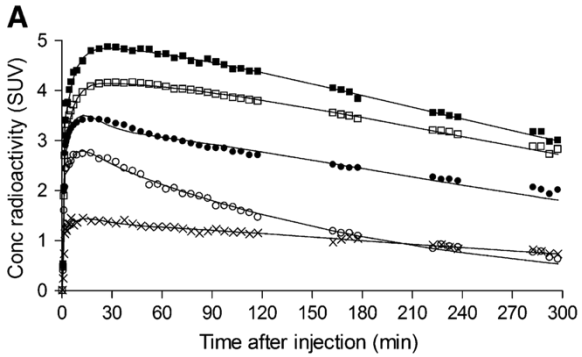


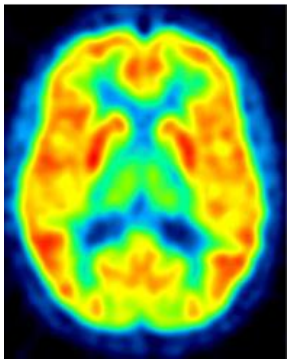
The subject's statistical map

Within-subject: comparison between PET and fMRI data

1. Traditional PET



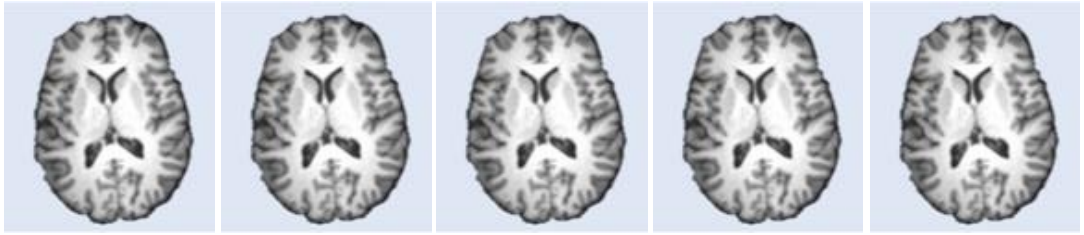




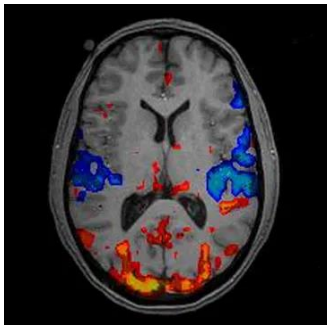
Density
e.g., glucose uptake

2. fMRI

Time



Task



Statistical map

Why is 1st level analysis?

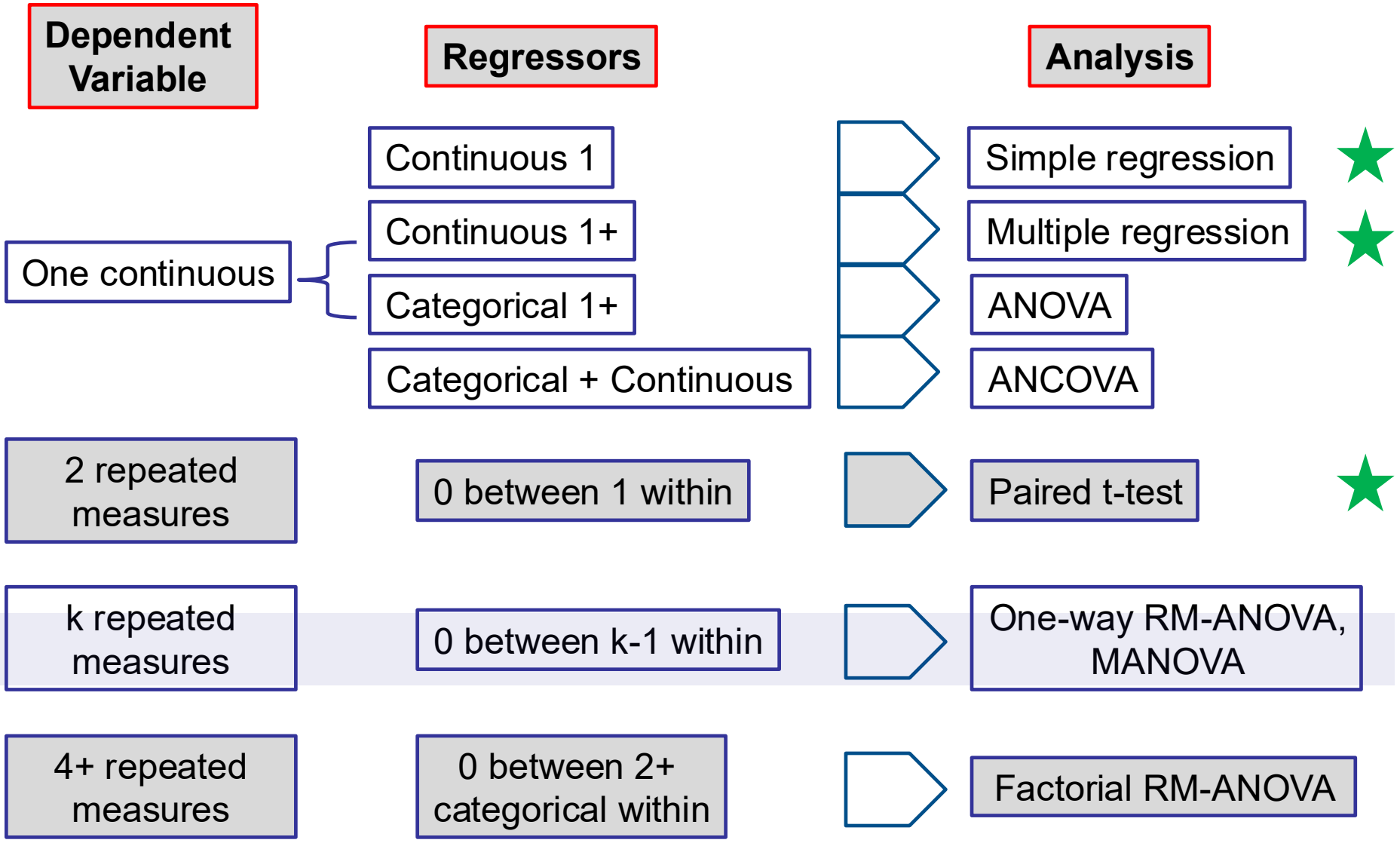
- BOLD signals are dominated by noise:

  physiological factors (breathing, heart rate), head movement, scanner instabilities, magnetic susceptibility artifacts, and neuronal variability, leading to low signal-to-noise ratio

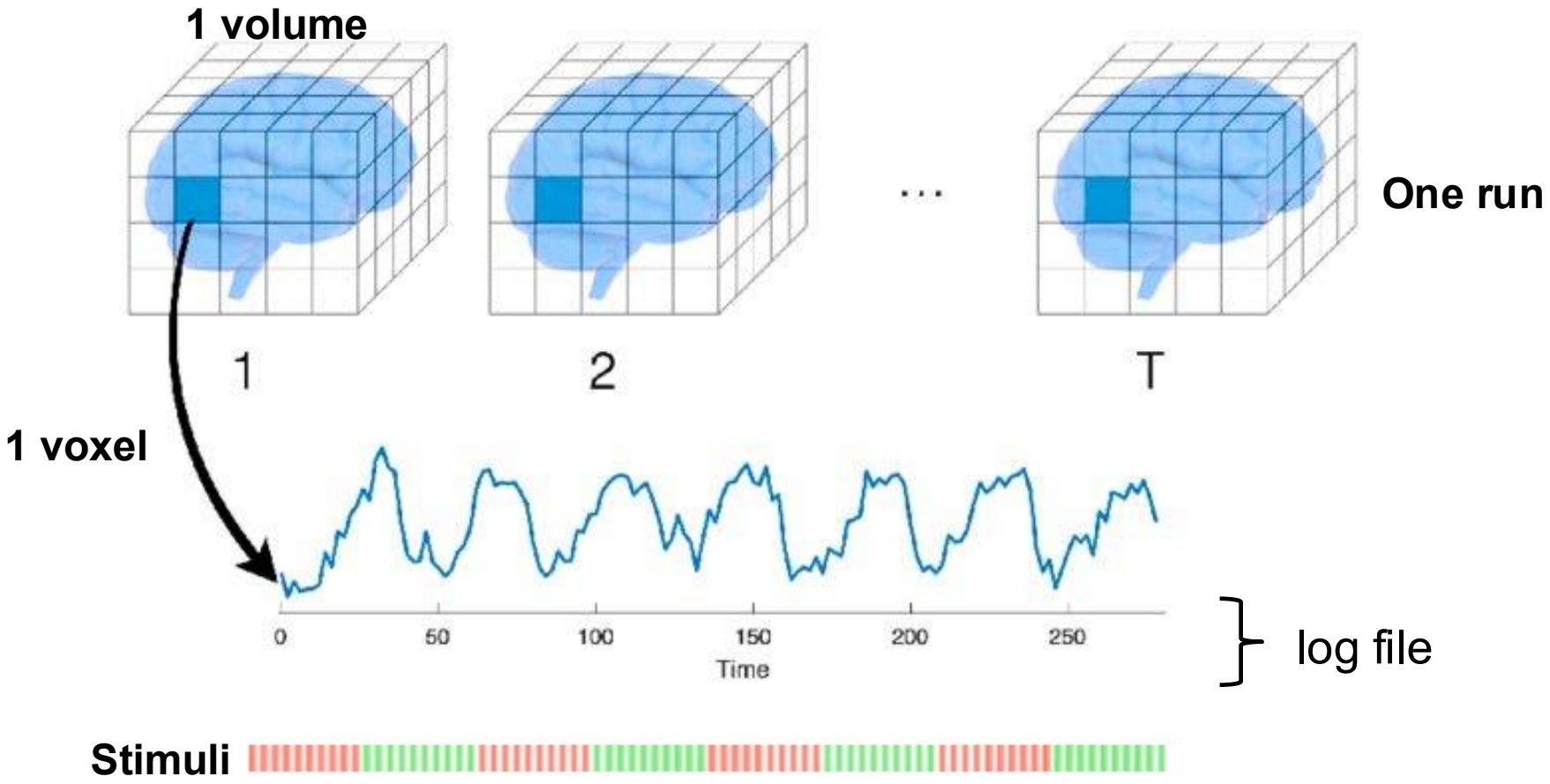
  >> preprocessing NOT enough!

- Multiple repeated exposure to stimuli to increase signal-to-noise ratio.
- Statistical analysis to extract the signal-associated brain responses **>> statistical map**

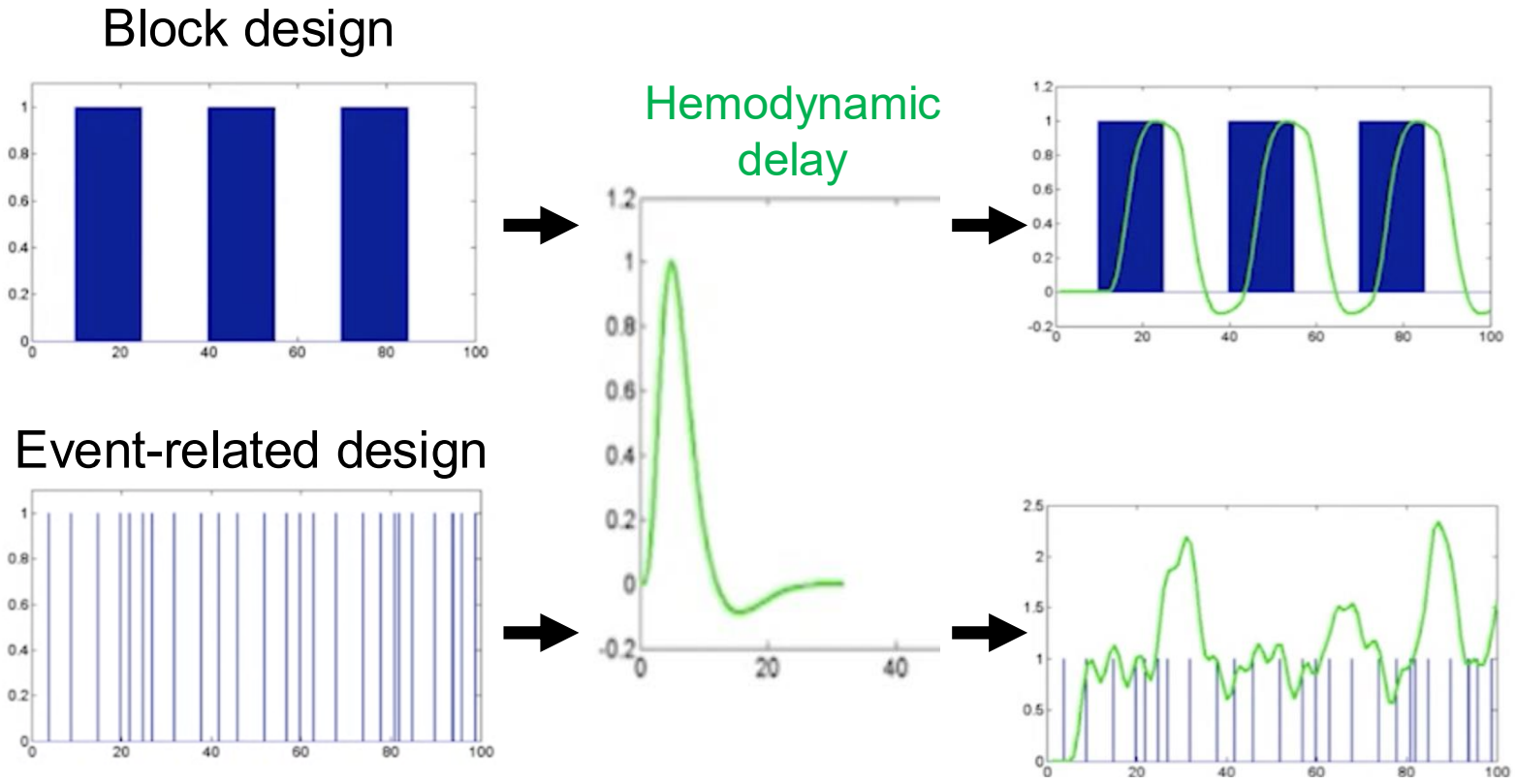
The general linear model (GLM) family



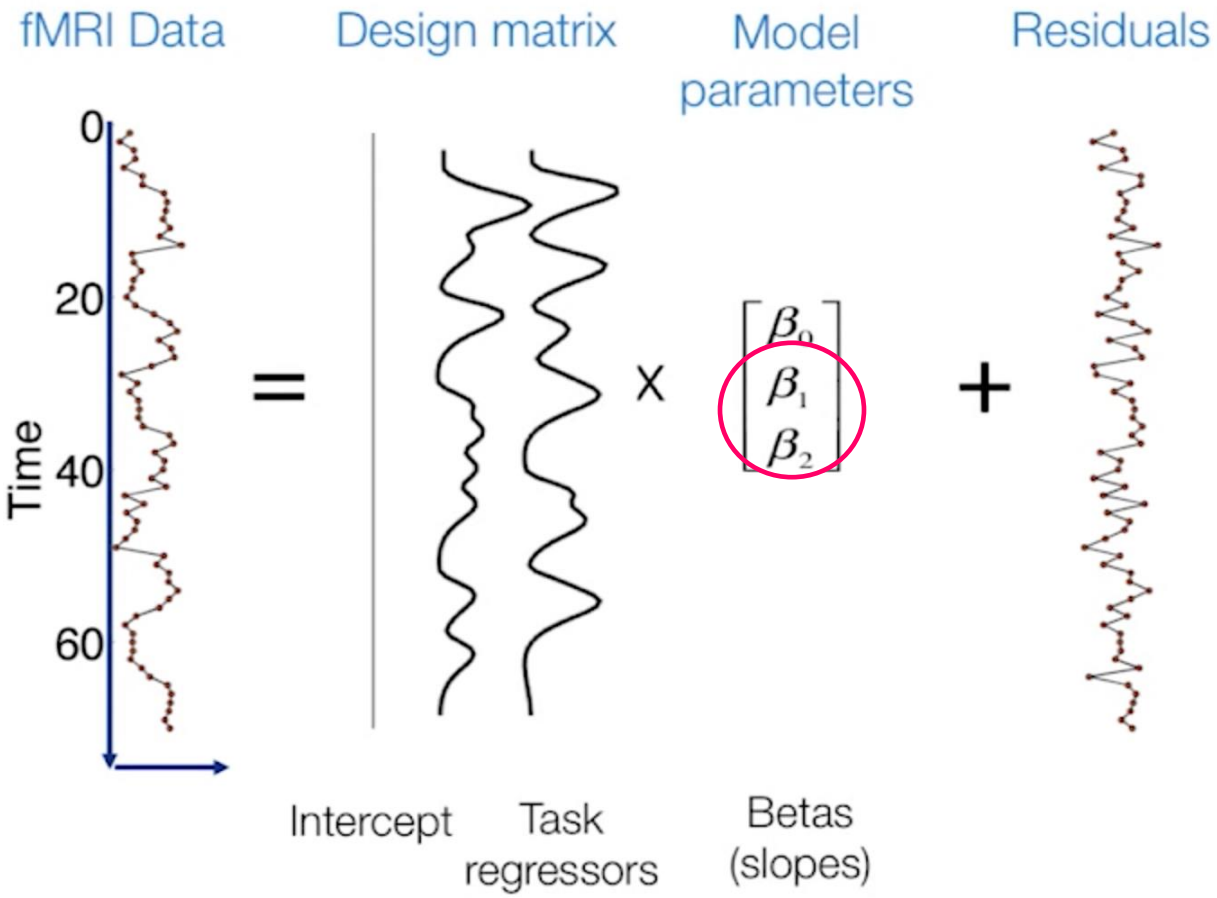
Voxel-level data modelling



- BOLD responses are delayed: **peak at 4-6 s** and **baseline 20-30 s**.
- Convolved with the hemodynamic response function (**HRF**)
- The linear time-invariant (**LTI)** system



Event-related design: two continuous regressors (laughter vs. scrambled laughter regressors)



Four example studies

1. Social laughter experiment
2. Naturlistic movie stimuli
3. Repeated measure food-reward responses
4. Resting states

The laughter experiment

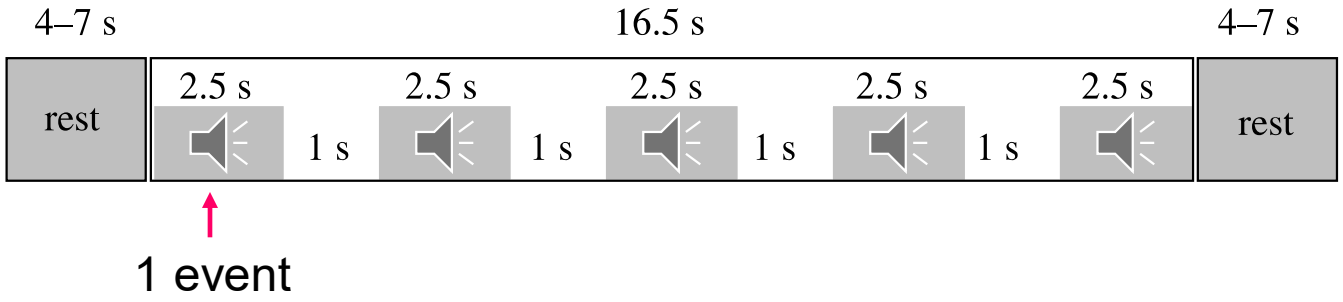
Laughter is a contagious behavioural stimulus that is commonly used to study social brain functions. We have studied the social brain functions of participants with high psychopathy or autism traits.

>> Sun L., et al., Cerebral Cortex, Volume 33, Issue 2, 15 January 2023

Four stimuli types:

Laughter / Crying vocalization /
Scrambled laughter / Scrambled Crying

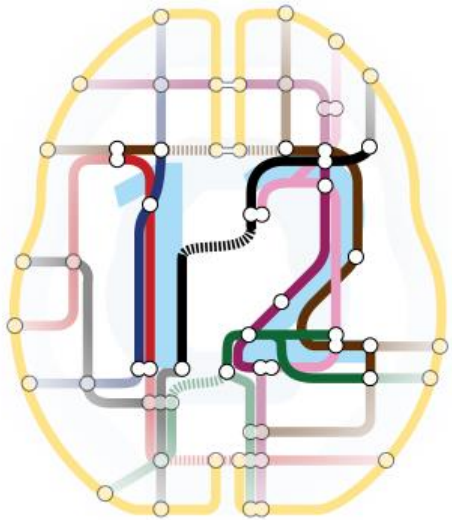
Block (also event-related) design



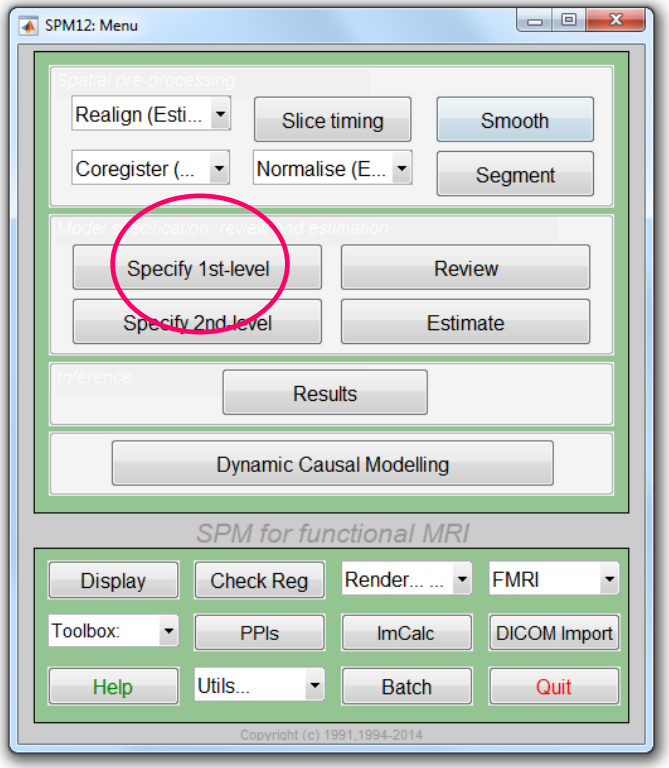
The 16.5 s block contains 5 Laughter, crying, or scrambled sound clips.

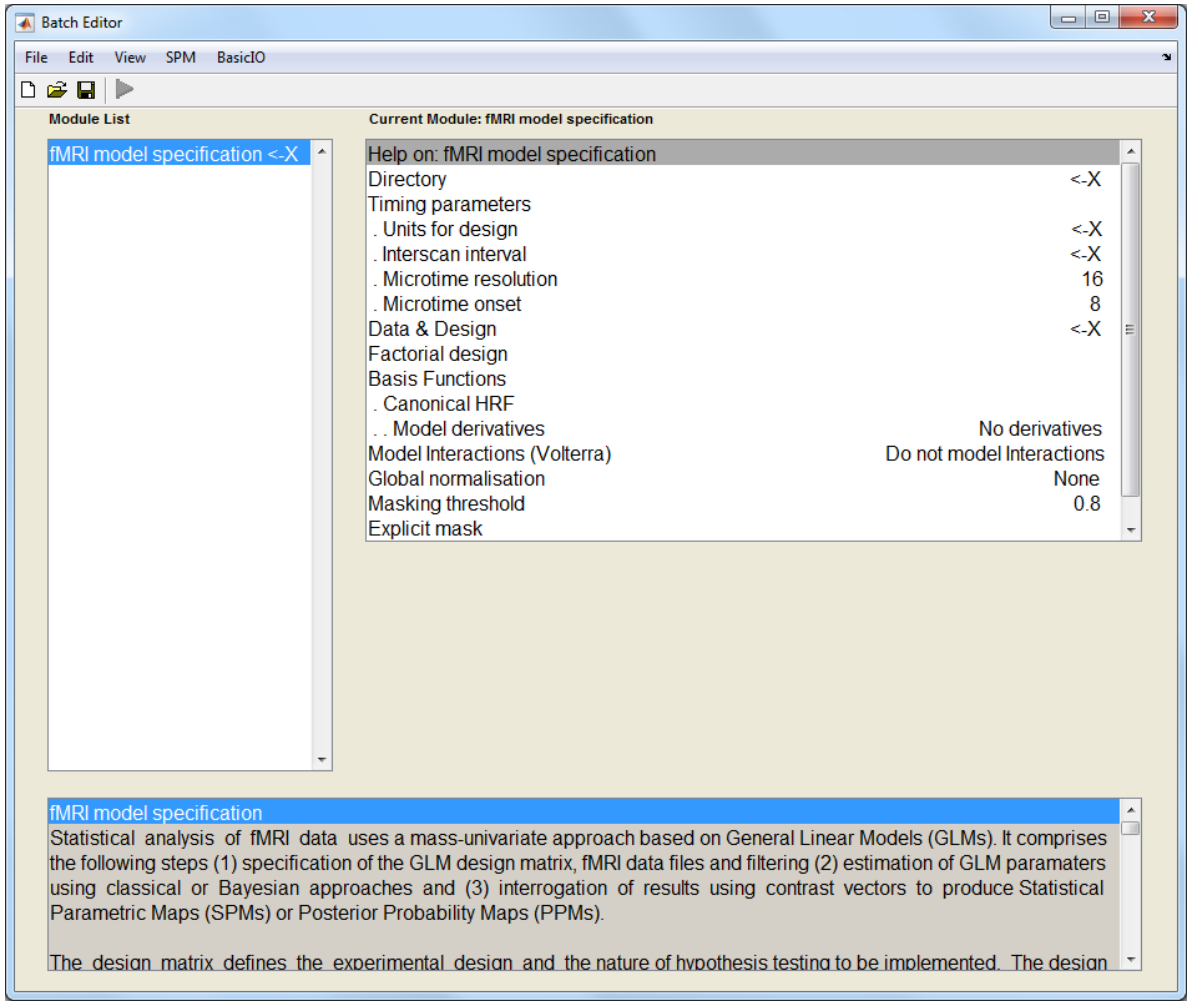
SPM12

- SPM - theoretical concepts of Statistical Parametric Mapping in a complete analysis package.
- Run in matlab
- See more information: https://www.fil.ion.ucl.ac.uk/spm/software/spm12/

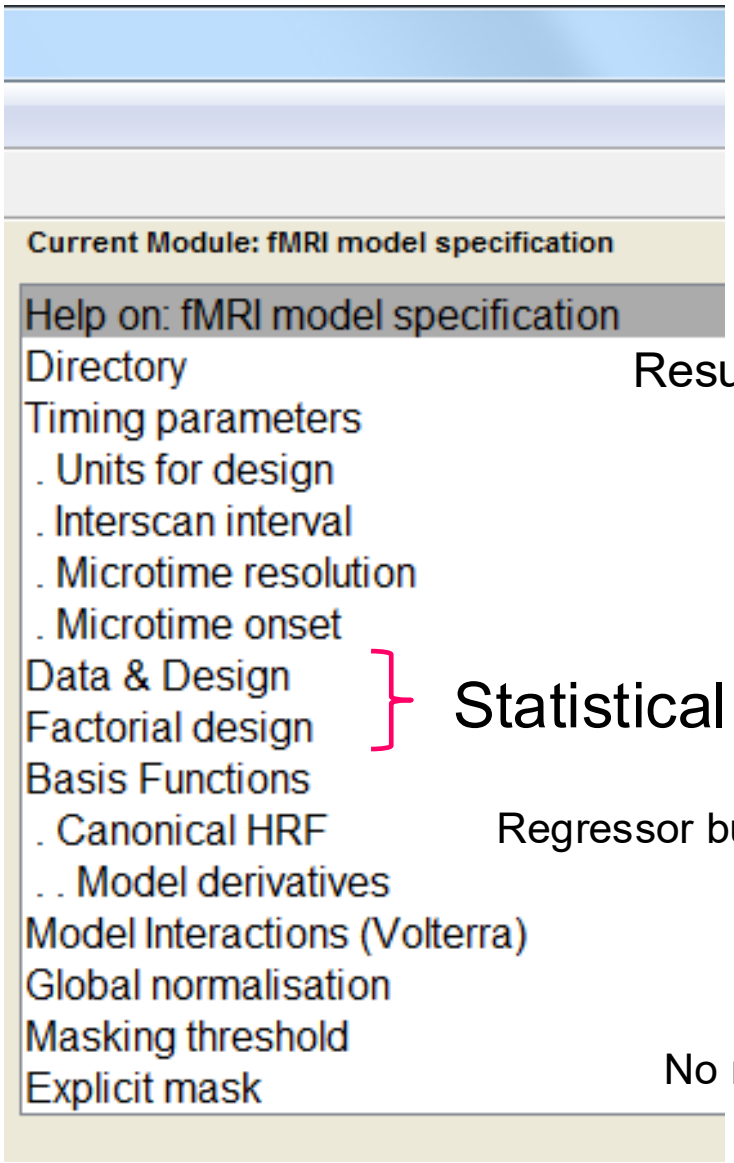


Operation in SPM12





SPM12: parameter setting



Result to store

seconds
2.6

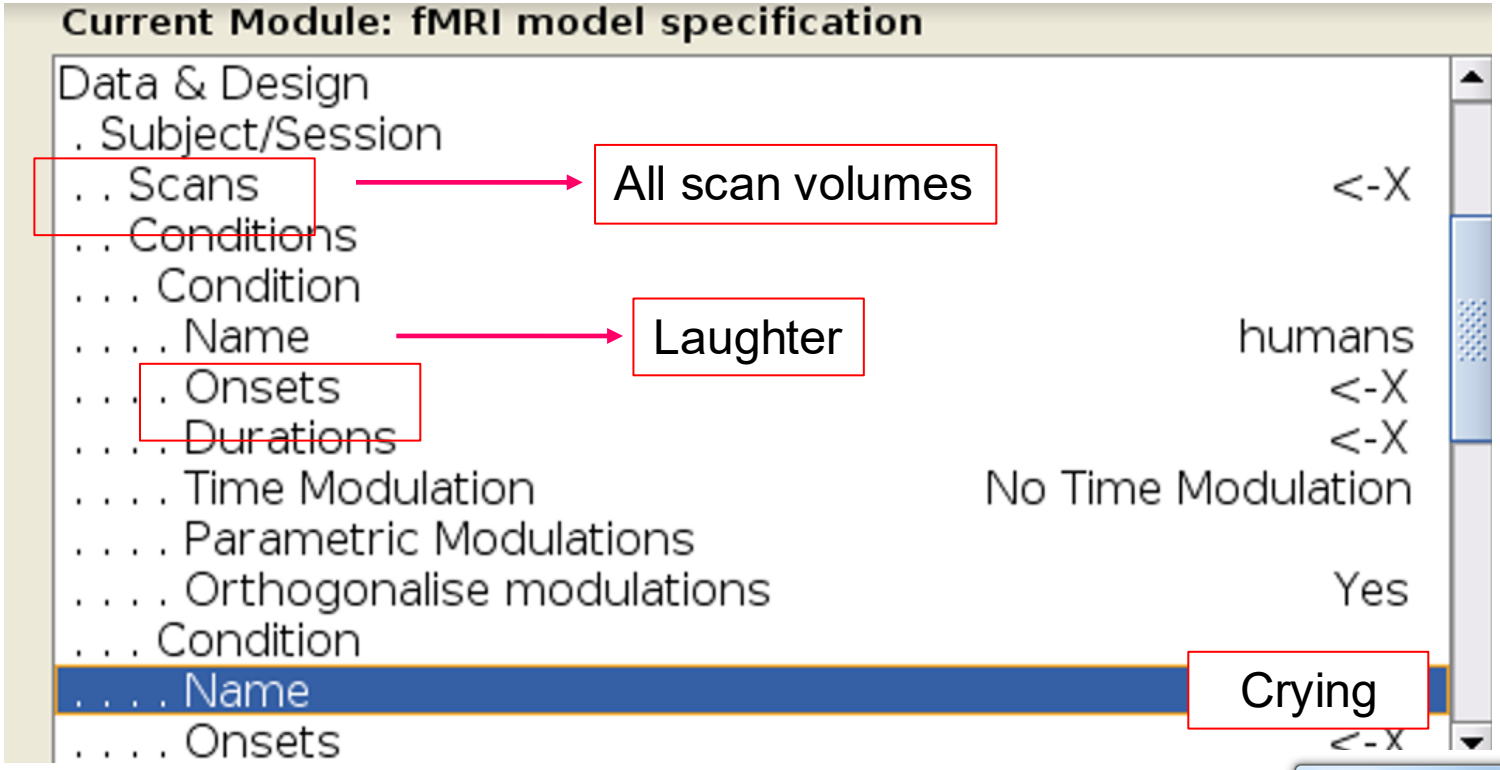
Basic settings

Statistical model

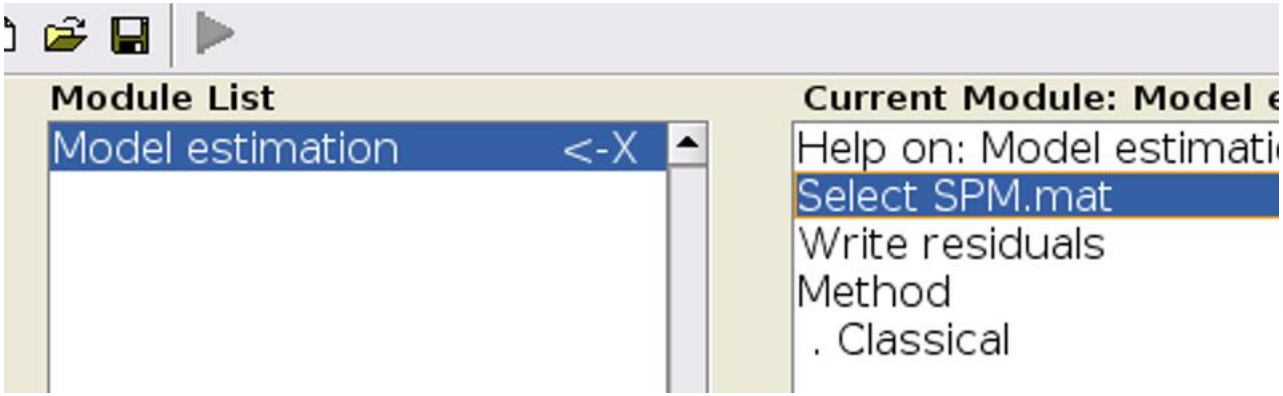
Regressor building

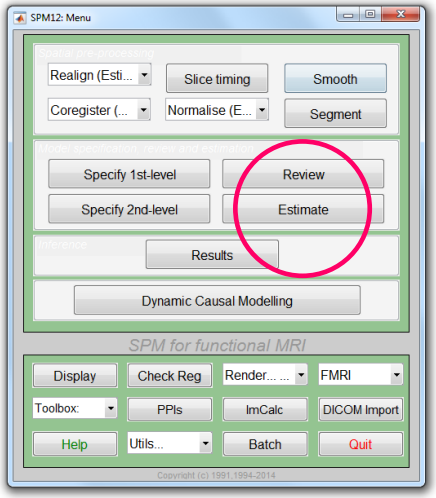
Leave as default,
or specify if necessary

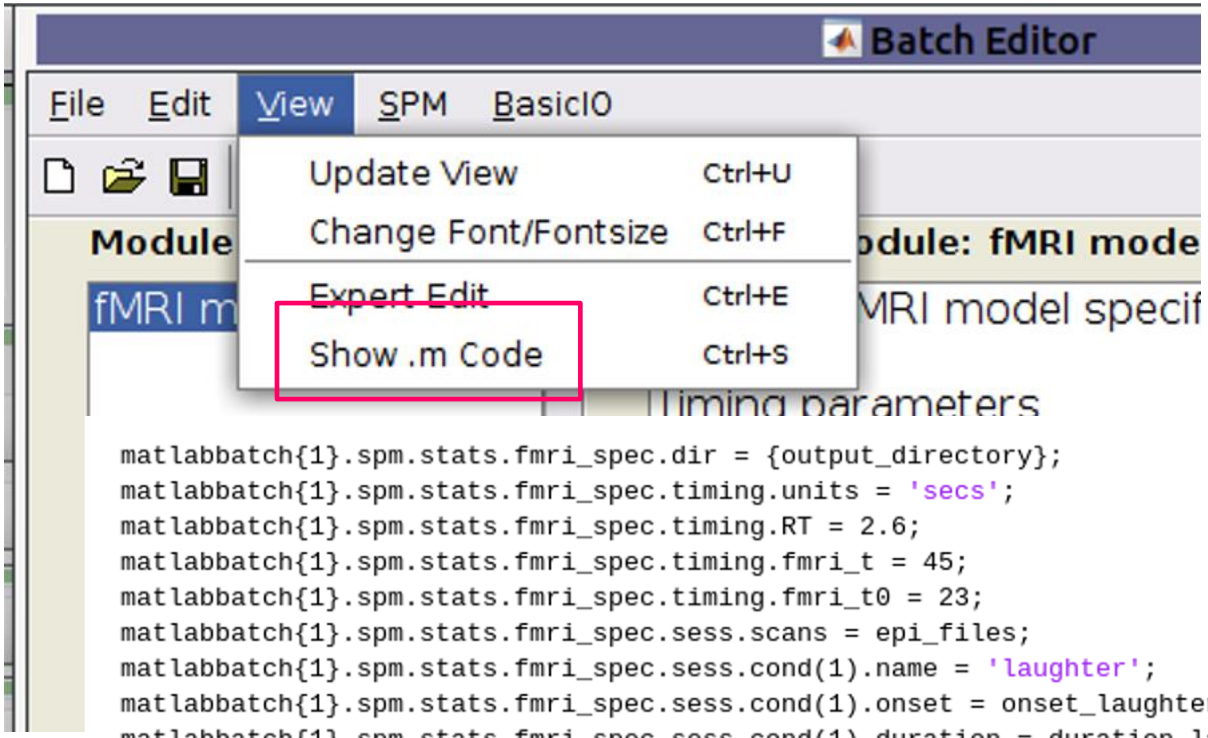
No masks



Data estimation





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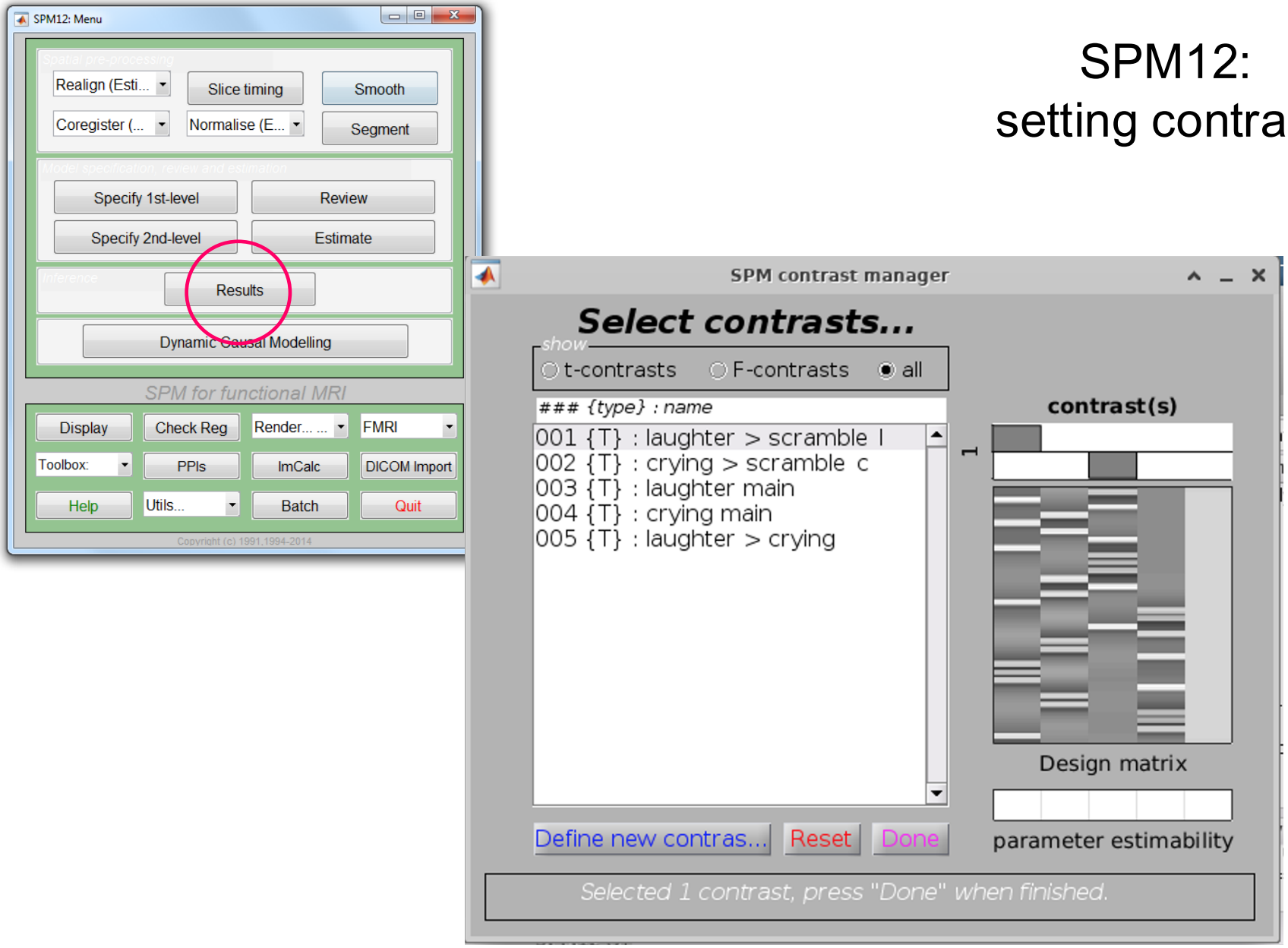
```

SPM12: setting contrasts

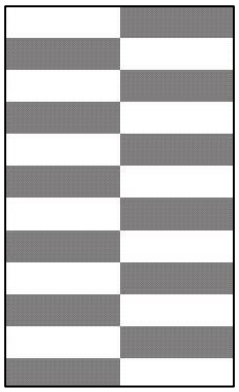


Contrasts

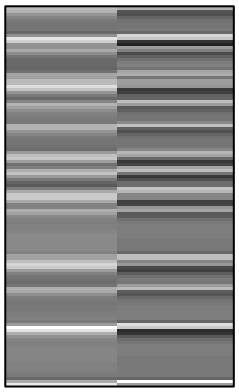
Experimental conditions: stimuli or interest vs. control stimuli

- Your interest is often the difference between the two conditions, which is "contrast"
- You can calculate the difference, sum or separately each conditions, which are calculated by different linear contrasts.

- We only introduce T contrast in this lecture ! !



Block design



Event-related design

Design matrix in SPM 12

Difference between conditions

[1 -1] = “Con1 > Con2”

[-1 1] = “Con1 < Con2”

Separately

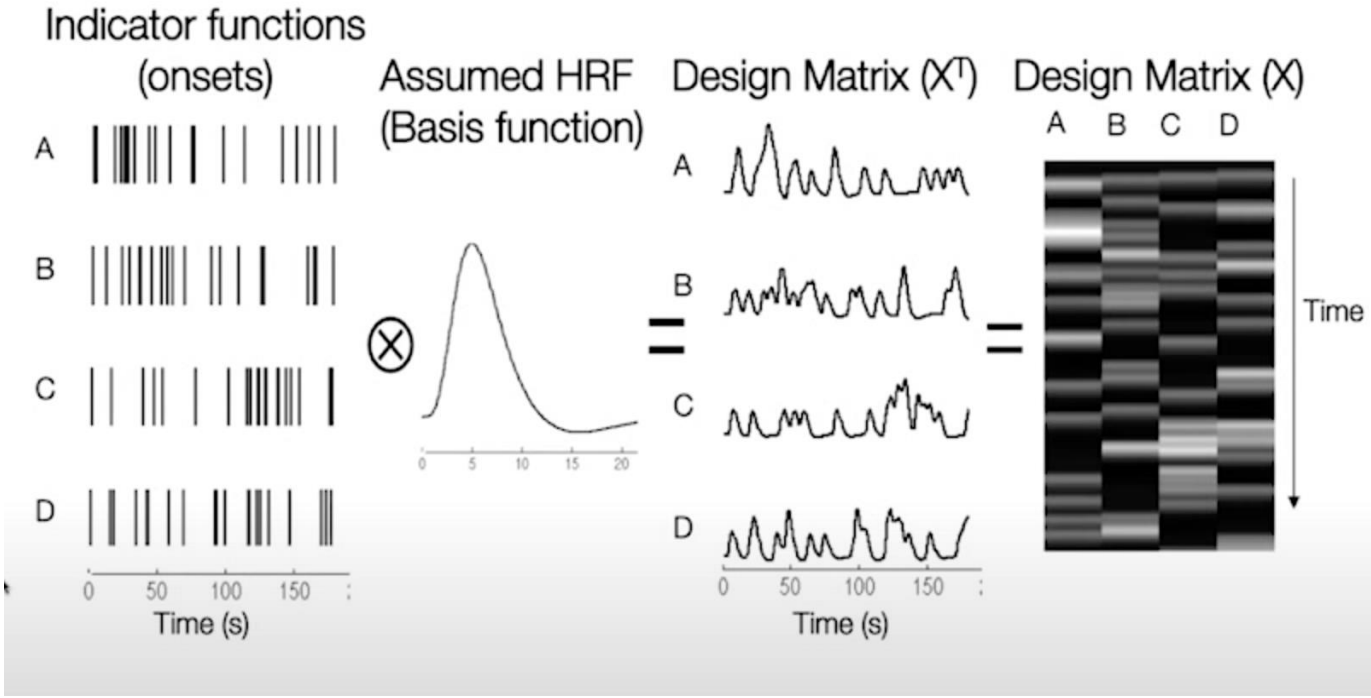
[1 0] or [-1 0] = “main effect Con1”

[0 1] or [0 -1] = “main effect Con2”

Sum

[1 1] or [-1 -1]

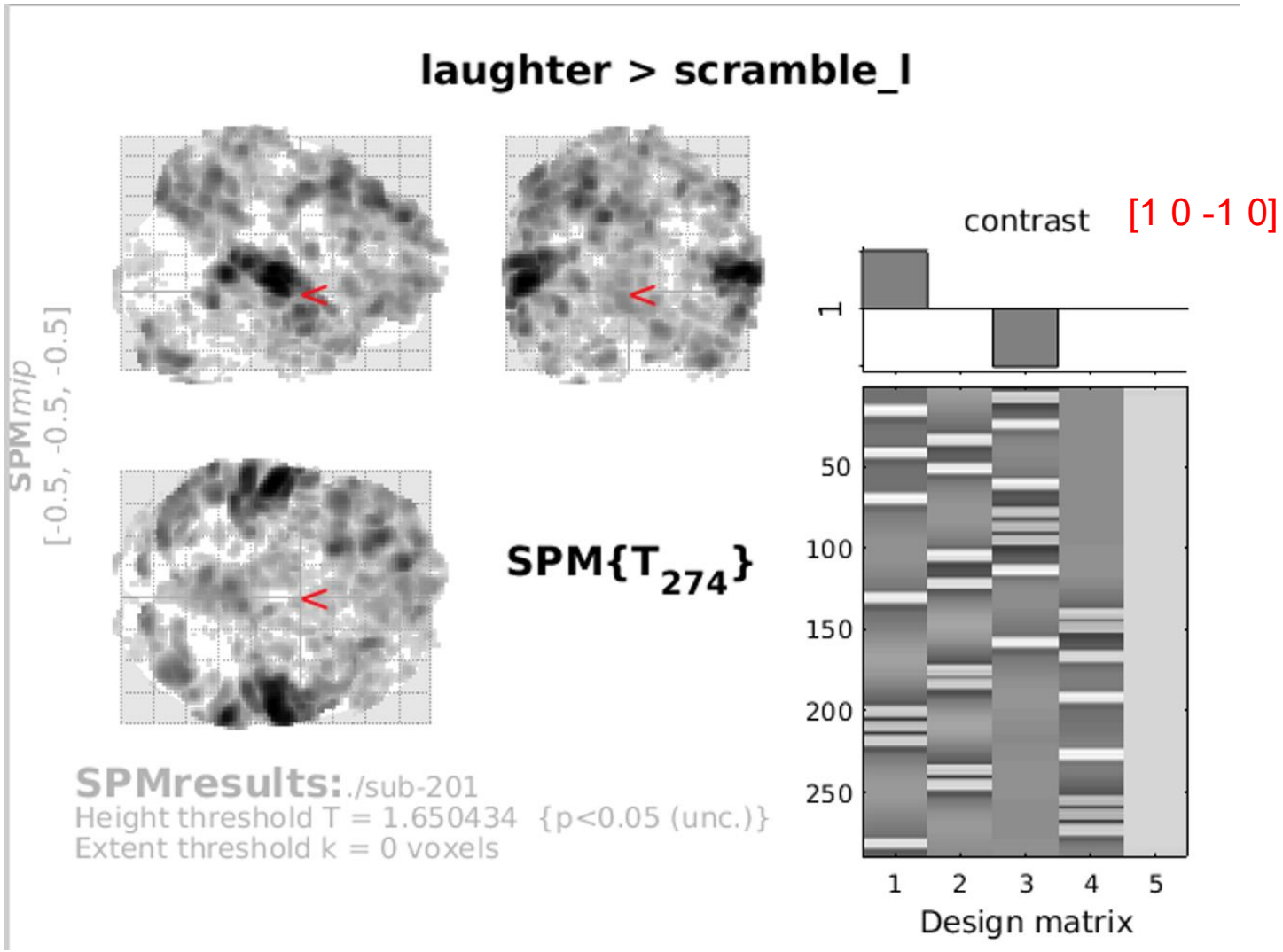
More regressors



- [1 1 -1 -1] : (A+B) > (C+D)
- [1 -1 1 -1] : (A+C) > (B+D)
- [1 0 0 0] : main effect of A
- [1 1 0 0] : Sum of (A+B) vs the mean of the signal

  ….

SPM12: result



Example 2: Naturalistic stimuli

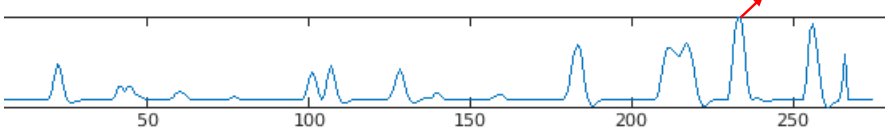
Naturalistic fMRI offers **ecological validity**, engages **complex brain functions**, **richer data**, **better participant engagement**, etc.

>> Santavirta S. et al., NeuroImage, Volume 272, 15 May 2023, 120025
>> Nummenmaa L., et al., Cerebral Cortex, Volume 31, Issue 9, September 2021, Pages 4104–4114

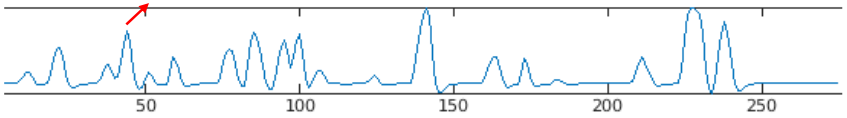
Movie-based fMRI

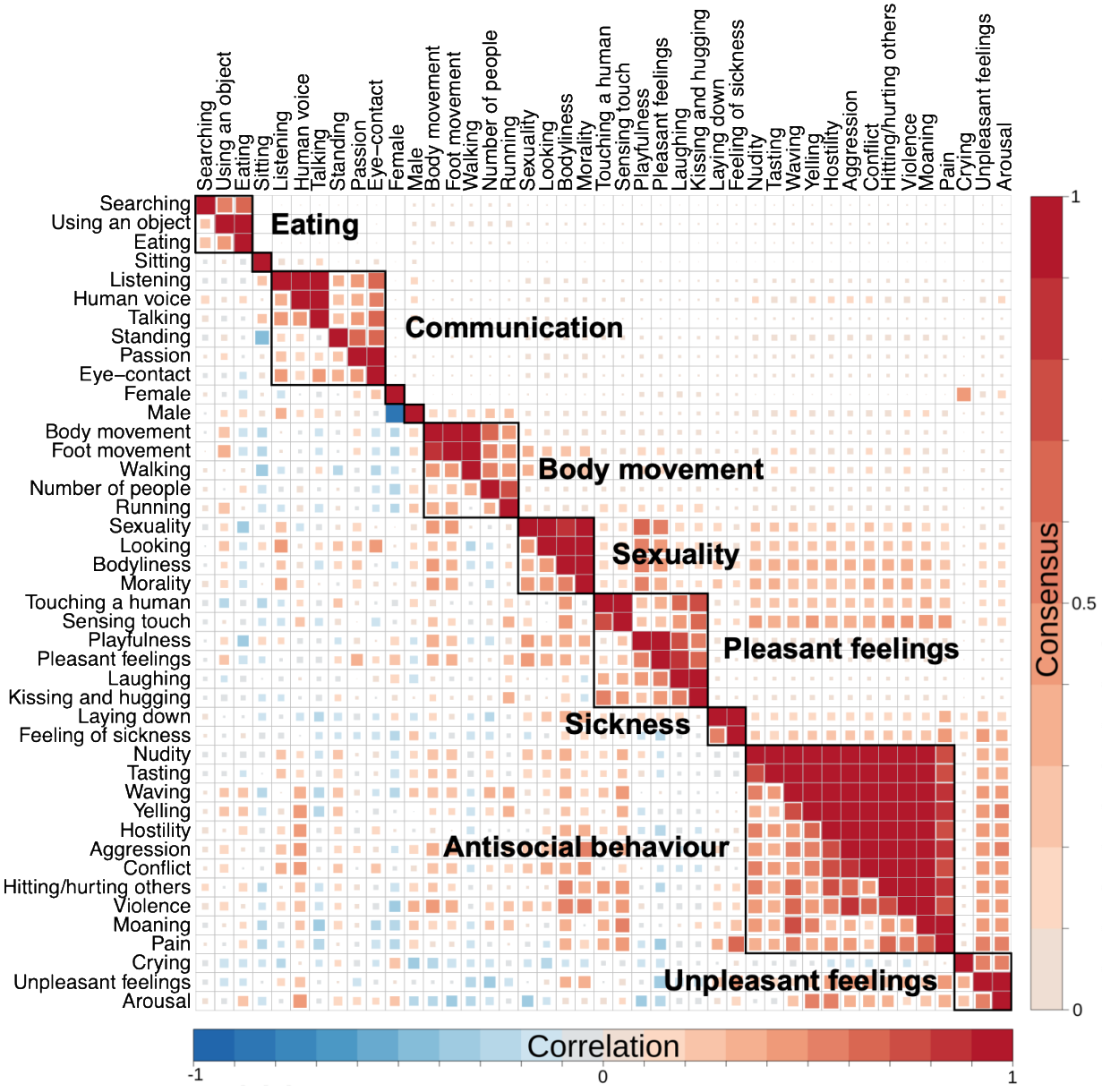
- ✓ Ratings of different dimensions (social, emotional, neutral, objective…)
- ✓ Each regressor should contain certain number of stimuli. CAN NOT be too small number!

Self-control



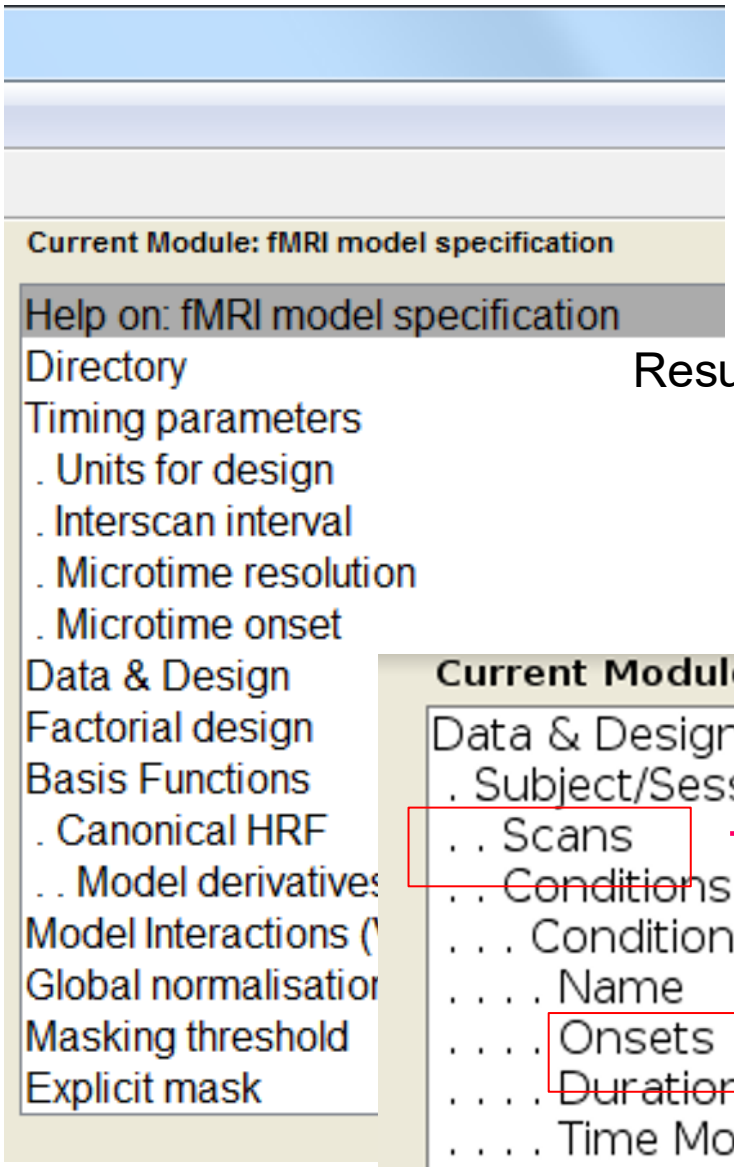
Wanting





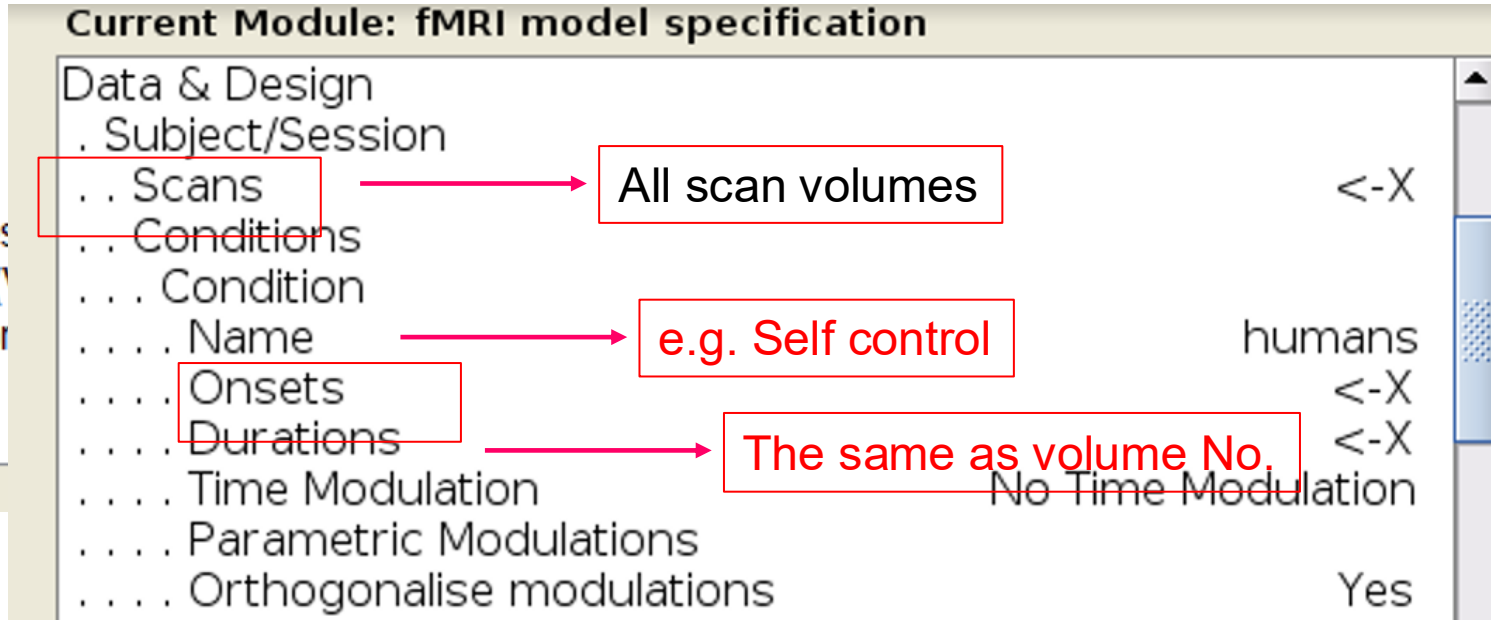
PCA analysis

SPM12: parameter setting

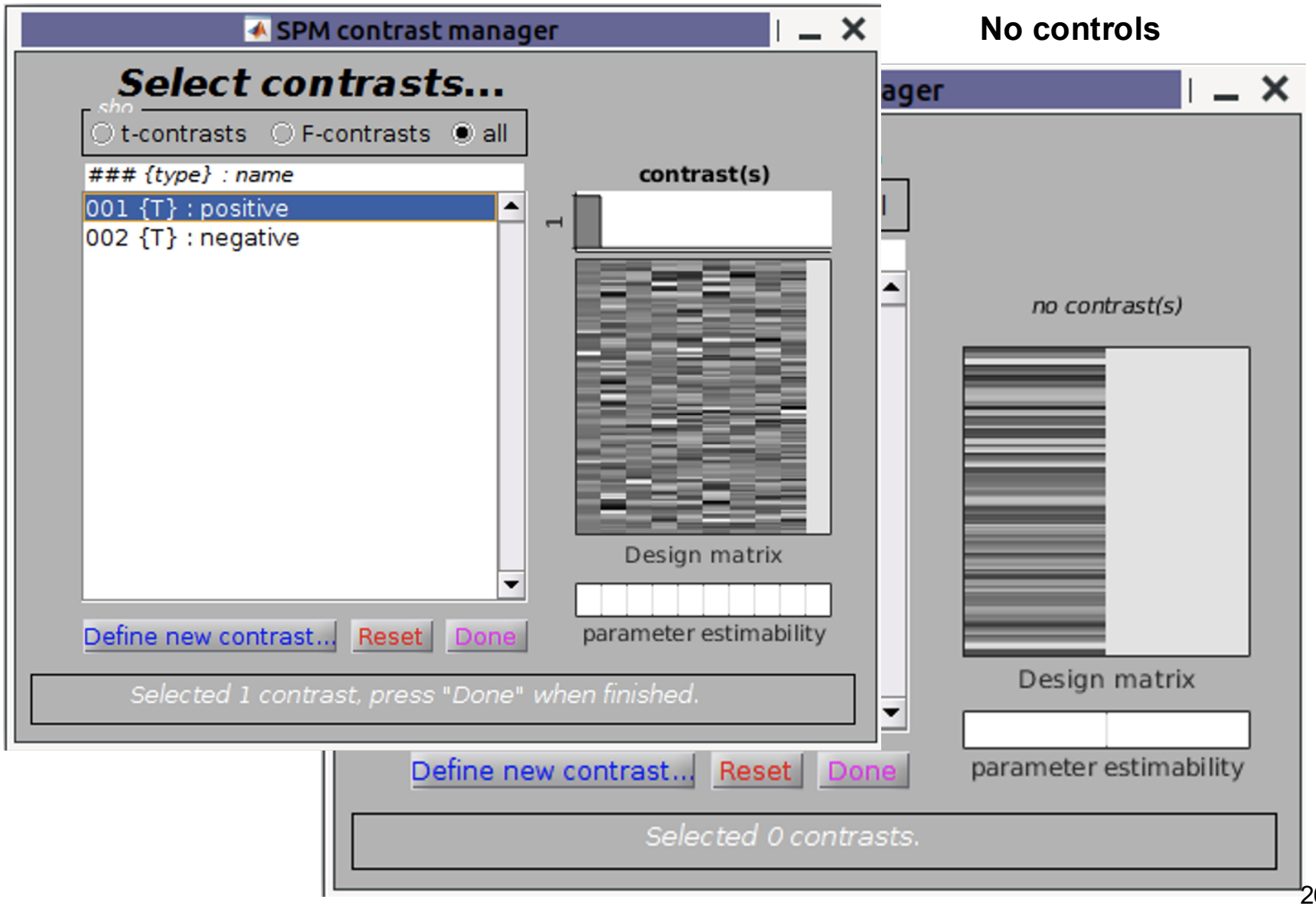


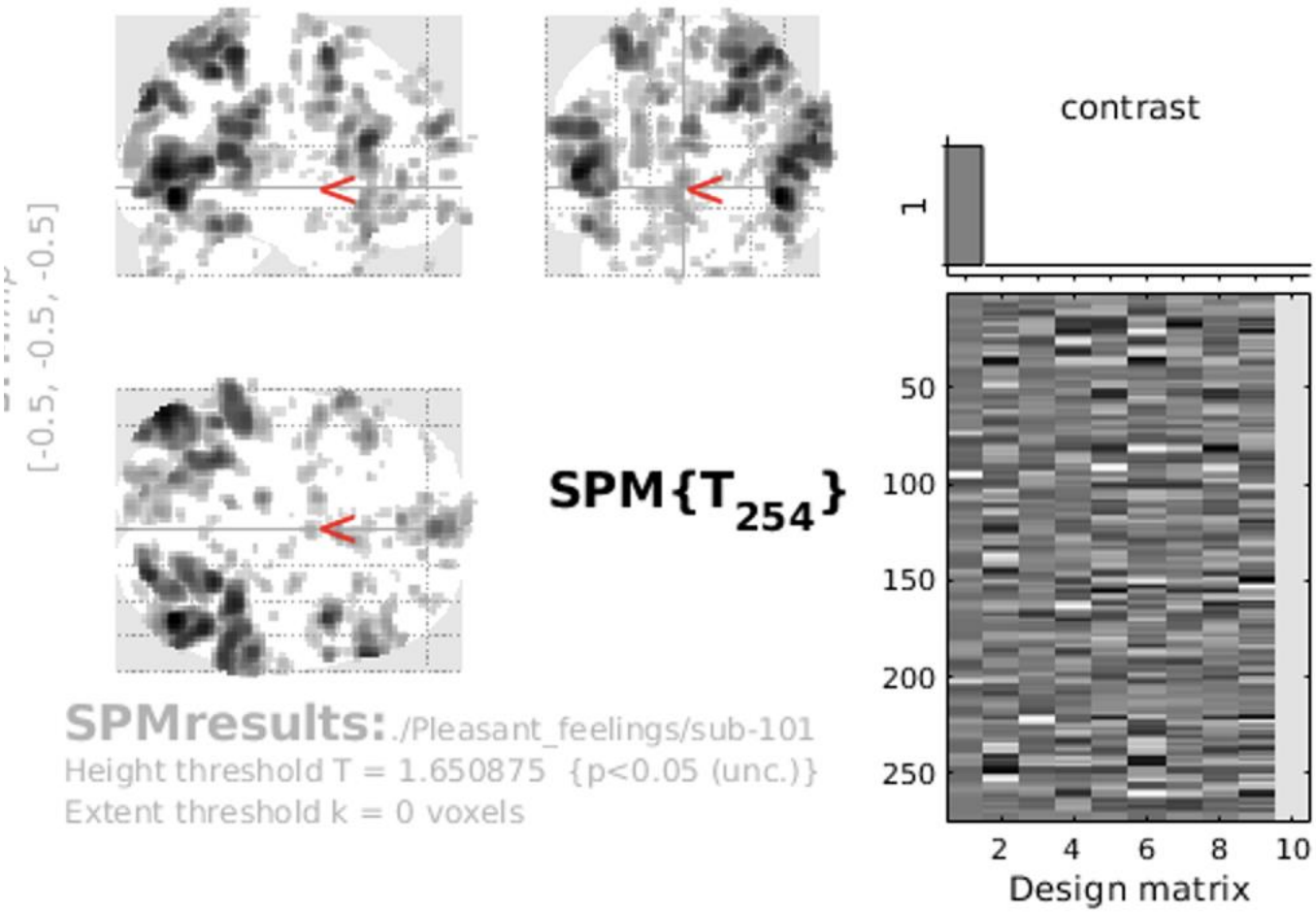
Result to store

scan } Dependent variables



Controlling for low-level regressors





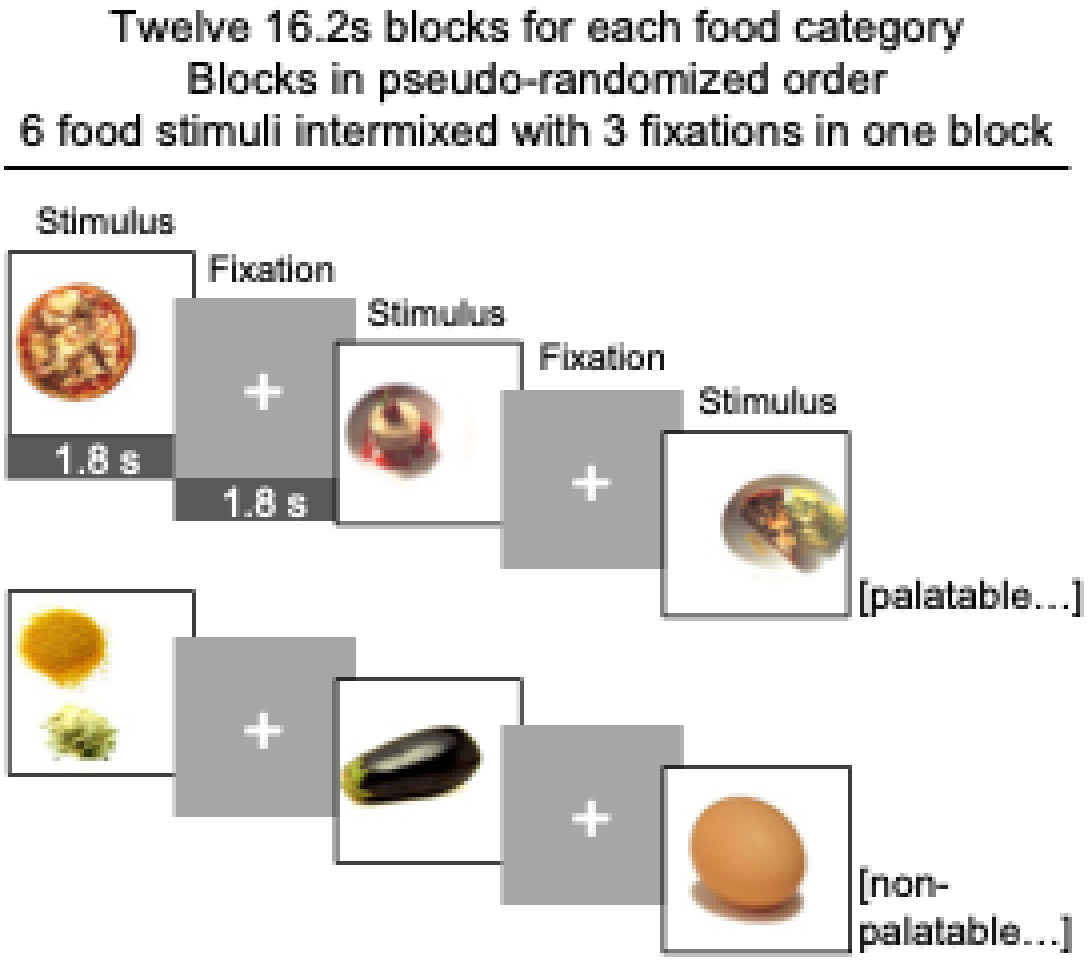
Statistics: ***p-values adjusted for search volume***

set-level		cluster-level				peak-level					mm	mm	mm
p	c	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	k_E	p_{uncorr}	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	T	$(Z_{=})$	p_{uncorr}			
1.000	**100**	**0.009**	**0.002**	**1576**	**0.000**	**0.026**	**0.025**	**5.21**	**5.07**	**0.000**	**46**	**-72**	**-6**
						0.211	0.055	4.67	4.57	0.000	48	-56	8
						0.701	0.100	4.23	4.15	0.000	54	-66	6
		0.034	**0.005**	**1272**	**0.000**	**0.070**	**0.034**	**4.97**	**4.85**	**0.000**	**-52**	**-76**	**6**

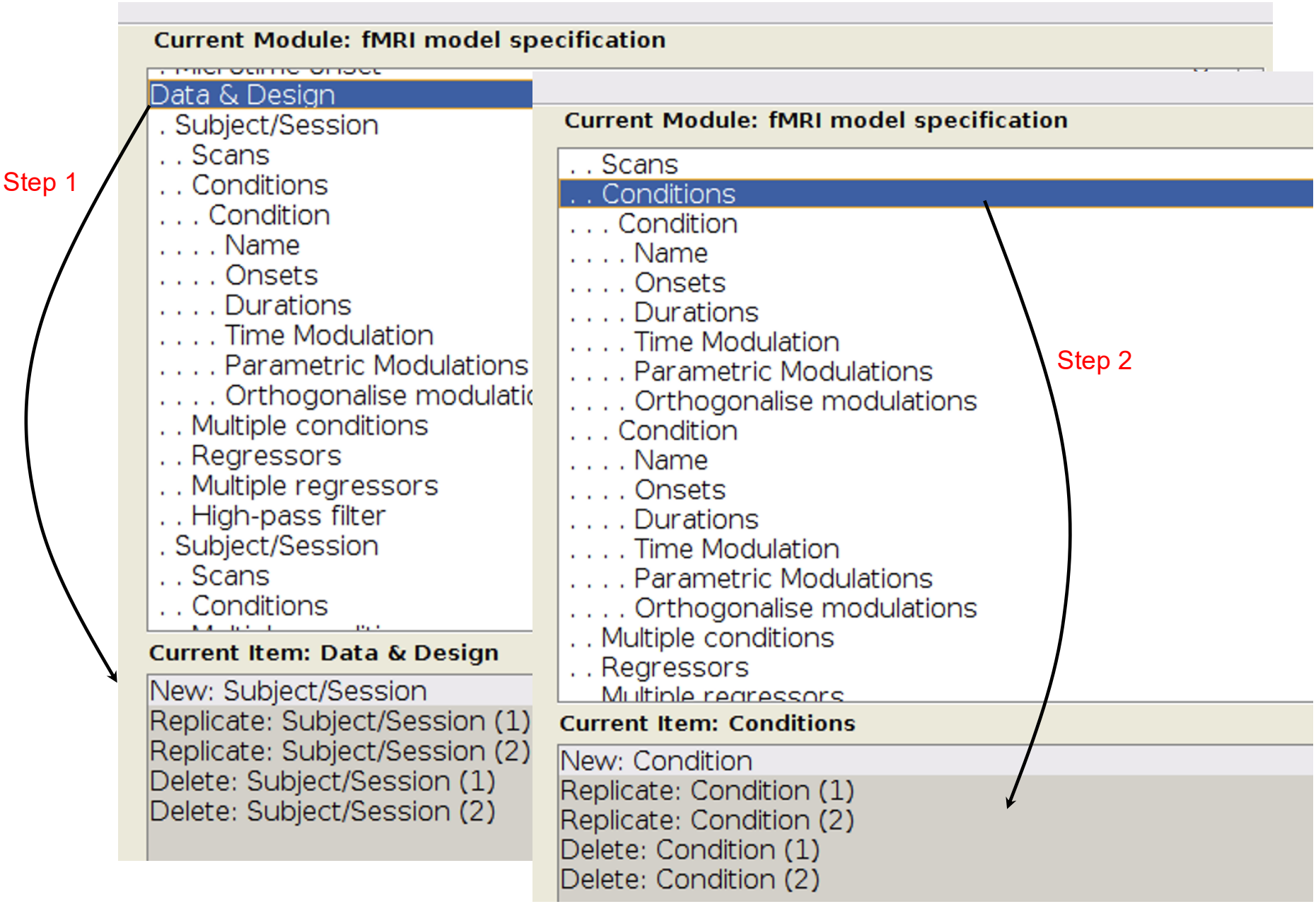
Example 3: Repeated measure food-reward

Food reward experiment has been used in decoding the brain conceptualizeion of satiation as induced by secretin hormone.

>> Lauri S., Sun L., et al., Nature Metabolism, volume 3, pages 798–809 (2021)



- Control condition vs. condition with infusion of secretin.
- Each subject **scanned twice** with fMRI: one in control condition, the other under intervention (secretin infusion).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Data & Design
. Subject/Session
. . Scans
. . Conditions
. . . Condition
. . . . Name
. . . . Onsets
. . . . Durations
. . . . Time Modulation
. . . . Parametric Modulations
. . . . Orthogonalise modulatic
. . Multiple conditions
. . Regressors
. . Multiple regressors
. . High-pass filter
. Subject/Session
. . Scans
. . Conditions
Current Item: Data & Design
New: Subject/Session
Replicate: Subject/Session (1)
Replicate: Subject/Session (2)
Delete: Subject/Session (1)
Delete: Subject/Session (2)
Step 1
Current Module: fMRI model specification
. . Scans
. . Conditions
. . . Condition
. . . . Name
. . . . Onsets
. . . . Durations
. . . . Time Modulation
. . . . Parametric Modulations
. . . . Orthogonalise modulations
. . . Condition
. . . . Name
. . . . Onsets
. . . . Durations
. . . . Time Modulation
. . . . Parametric Modulations
. . . . Orthogonalise modulations
. . Multiple conditions
. . Regressors
Current Item: Conditions
New: Condition
Replicate: Condition (1)
Replicate: Condition (2)
Delete: Condition (1)
Delete: Condition (2)
Step 2

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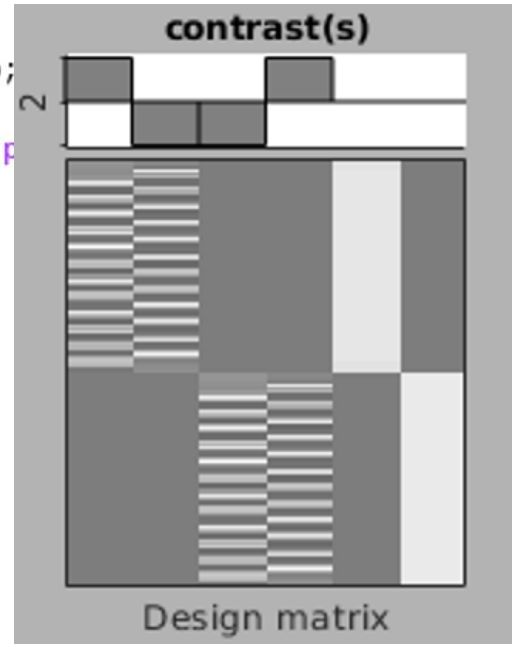

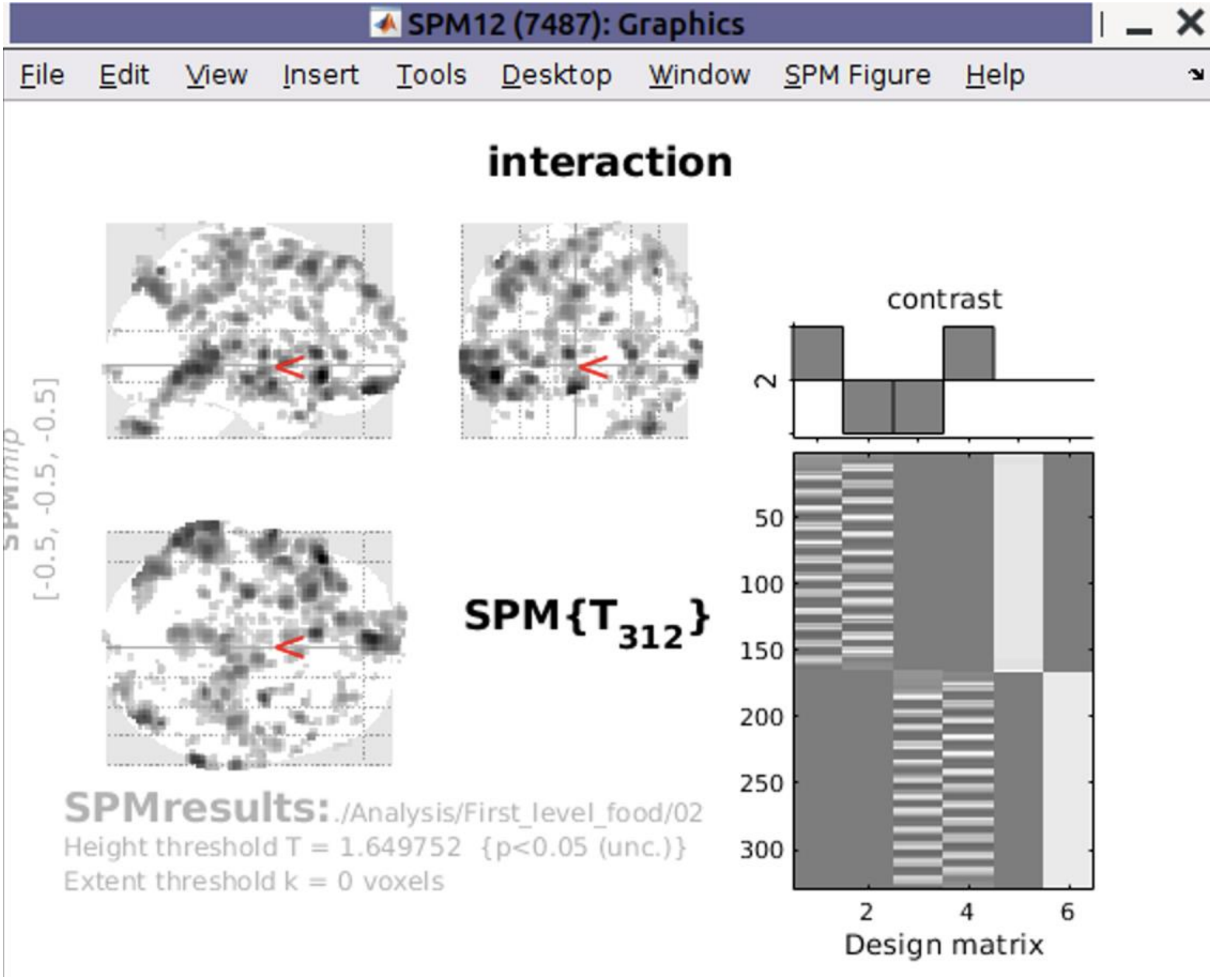
SPM12 (7487): Graphics
File Edit View Insert Tools Desktop Window SPM Figure Help
interaction
SPMmip
[-0.5, -0.5, -0.5]
SPM{T312}
contrast
2
50
100
150
200
250
300
2
4
6
Design matrix
SPMresults: ./Analysis/First_level_food/02
Height threshold T = 1.649752 {p<0.05 (unc.)}
Extent threshold k = 0 voxels

Example 4: resting state fMRI

- ReHo = regional homogeneity: larger value indicates a higher regional synchronization.
- ALFF = amplitude of low-frequency fluctuation: indicate the magnitude of neural activity
- **FC = functional connectivity (between ROIs): inter-regional correlations**

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DPARSF: a MATLAB toolbox for "pipeline" data analysis of resting-state fMRI

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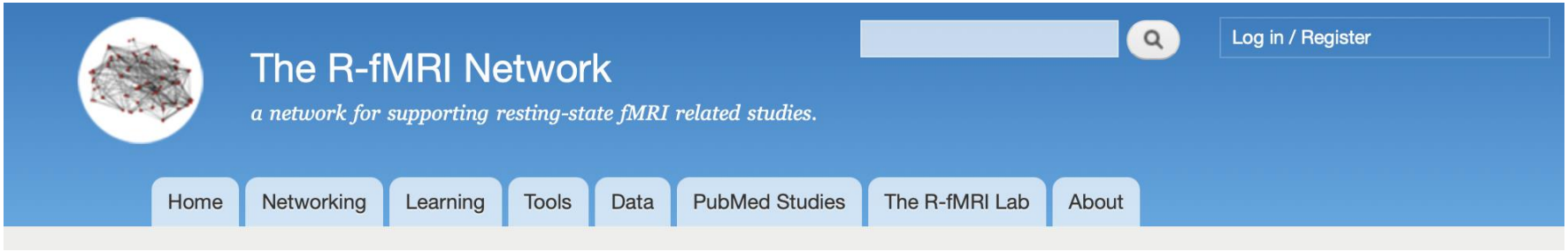
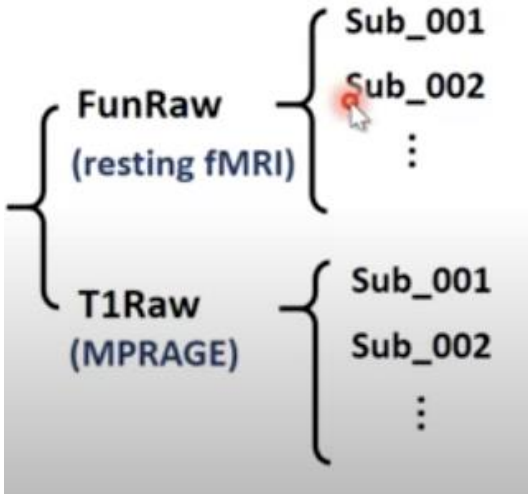
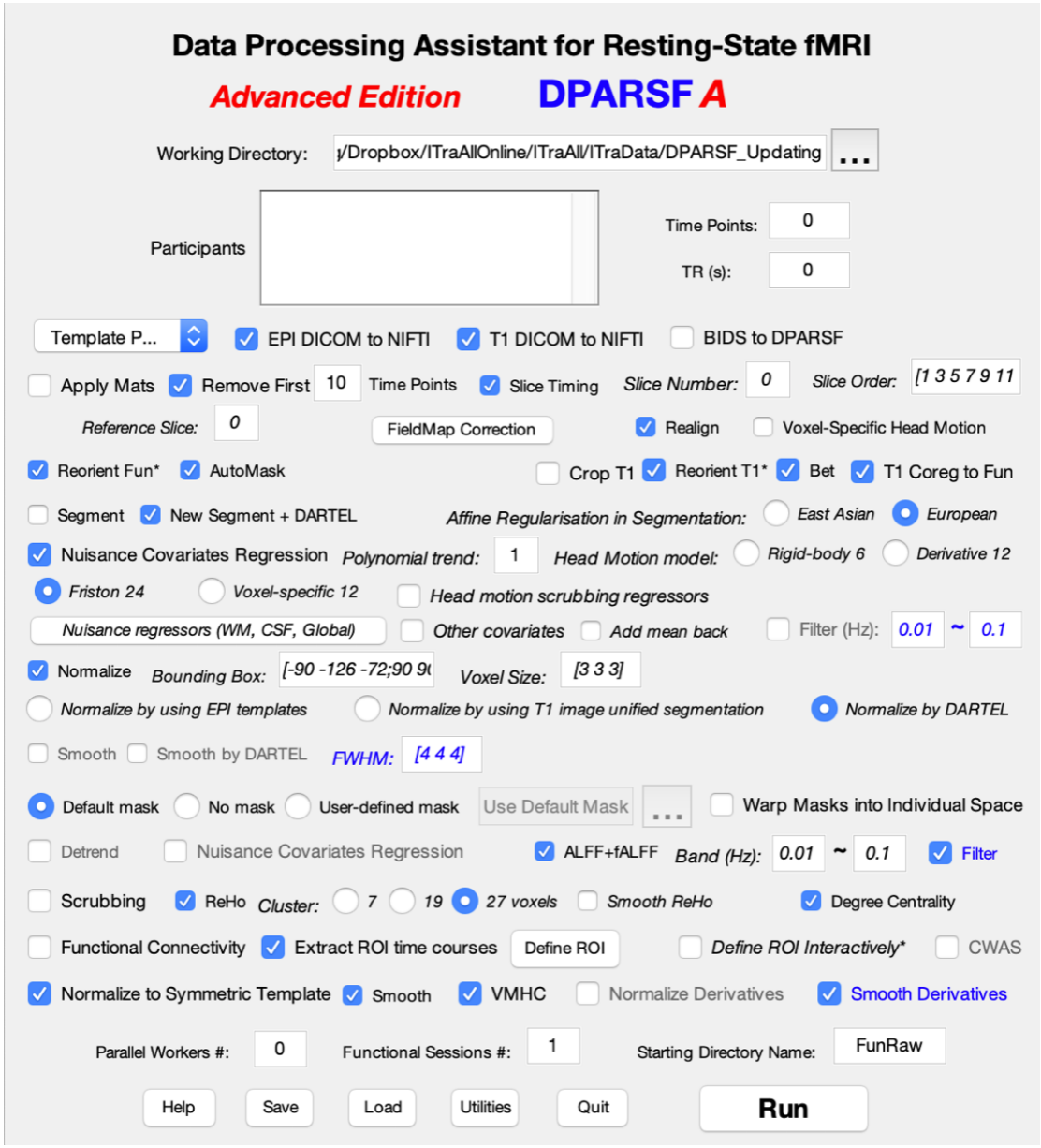
Toolbox for rs-fMRI analysis

- Matlab based
- Download DPARSF from: http://rfmri.org/DPARSF



Data folder


FunRaw
(resting fMRI)
Sub_001
Sub_002
T1Raw
(MPRAGE)
Sub_001
Sub_002


Data Processing Assistant for Resting-State fMRI
Advanced Edition
DPARSF A
Working Directory: /Dropbox/ITraAllOnline/ITraAll/ITraData/DPARSF_Updating
Participants
Time Points: 0
TR (s): 0
Template P...
EPI DICOM to NIFTI
T1 DICOM to NIFTI
BIDS to DPARSF
Apply Mats
Remove First 10 Time Points
Slice Timing
Slice Number: 0
Slice Order: [1 3 5 7 9 11
Reference Slice: 0
FieldMap Correction
Realign
Voxel-Specific Head Motion
Reorient Fun*
AutoMask
Crop T1
Reorient T1*
Bet
T1 Coreg to Fun
Segment
New Segment + DARTEL
Affine Regularisation in Segmentation:
East Asian
European
Nuisance Covariates Regression
Polynomial trend: 1
Head Motion model:
Rigid-body 6
Derivative 12
Friston 24
Voxel-specific 12
Head motion scrubbing regressors
Nuisance regressors (WM, CSF, Global)
Other covariates
Add mean back
Filter (Hz): 0.01 ~ 0.1
Normalize
Bounding Box: [-90 -126 -72;90 9(
Voxel Size: [3 3 3]
Normalize by using EPI templates
Normalize by using T1 image unified segmentation
Normalize by DARTEL
Smooth
Smooth by DARTEL
FWHM: [4 4 4]
Default mask
No mask
User-defined mask
Use Default Mask
Warp Masks into Individual Space
Detrend
Nuisance Covariates Regression
ALFF+fALFF
Band (Hz): 0.01 ~ 0.1
Filter
Scrubbing
ReHo
Cluster: 7 19 27 voxels
Smooth ReHo
Degree Centrality
Functional Connectivity
Extract ROI time courses
Define ROI
Define ROI Interactively*
CWAS
Normalize to Symmetric Template
Smooth
VMHC
Normalize Derivatives
Smooth Derivatives
Parallel Workers #: 0
Functional Sessions #: 1
Starting Directory Name: FunRaw
Help
Save
Load
Utilities
Quit
Run

Summary

- The first level analysis is **a within-subject analysis, necessary due to the low signal-noise ratios**.
- **Experimental design decides the statistical model**.
- We have showed 4 example studies on how to conduct the first level analysis.
- Using **Contrasts** to view the results
- Contrast images are ready for second level analysis.

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Thanks!

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