Statistical analysis of M/EEG Sensor- and Source-Level Data

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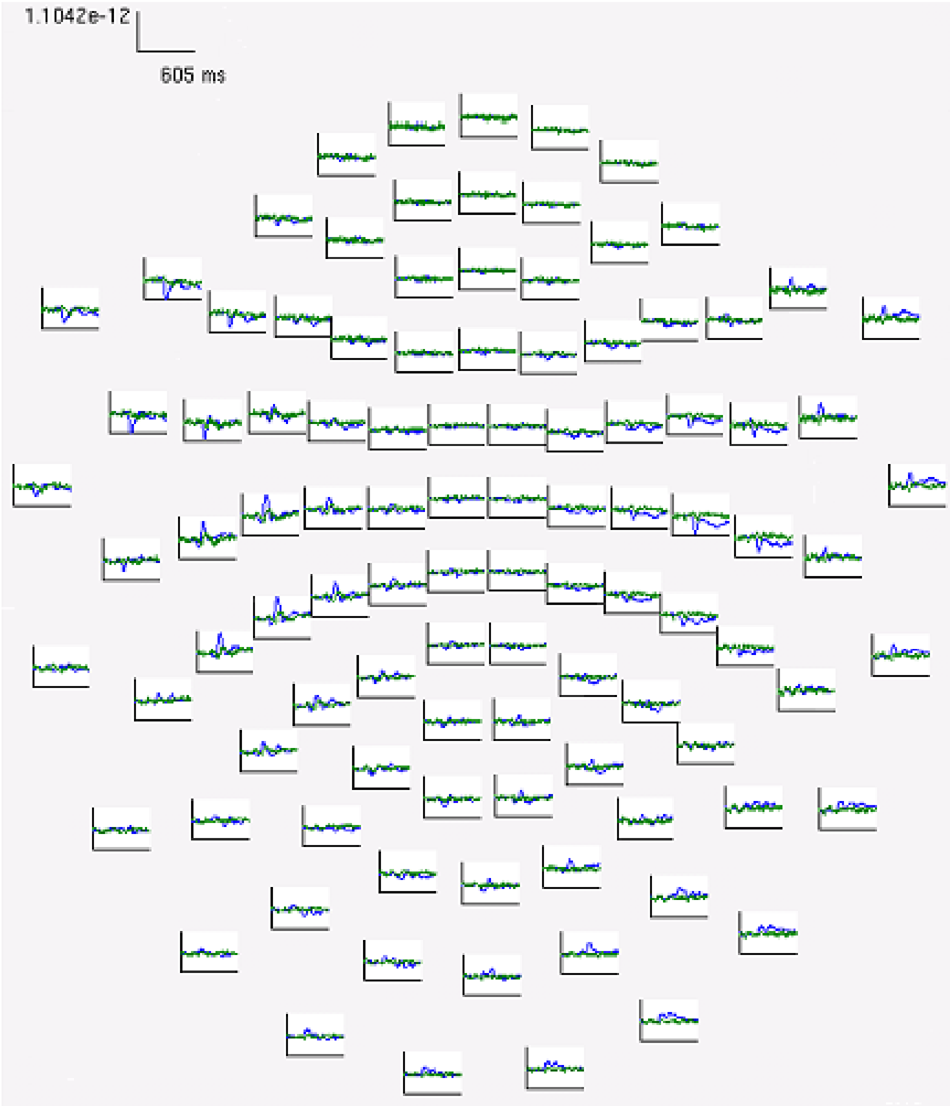
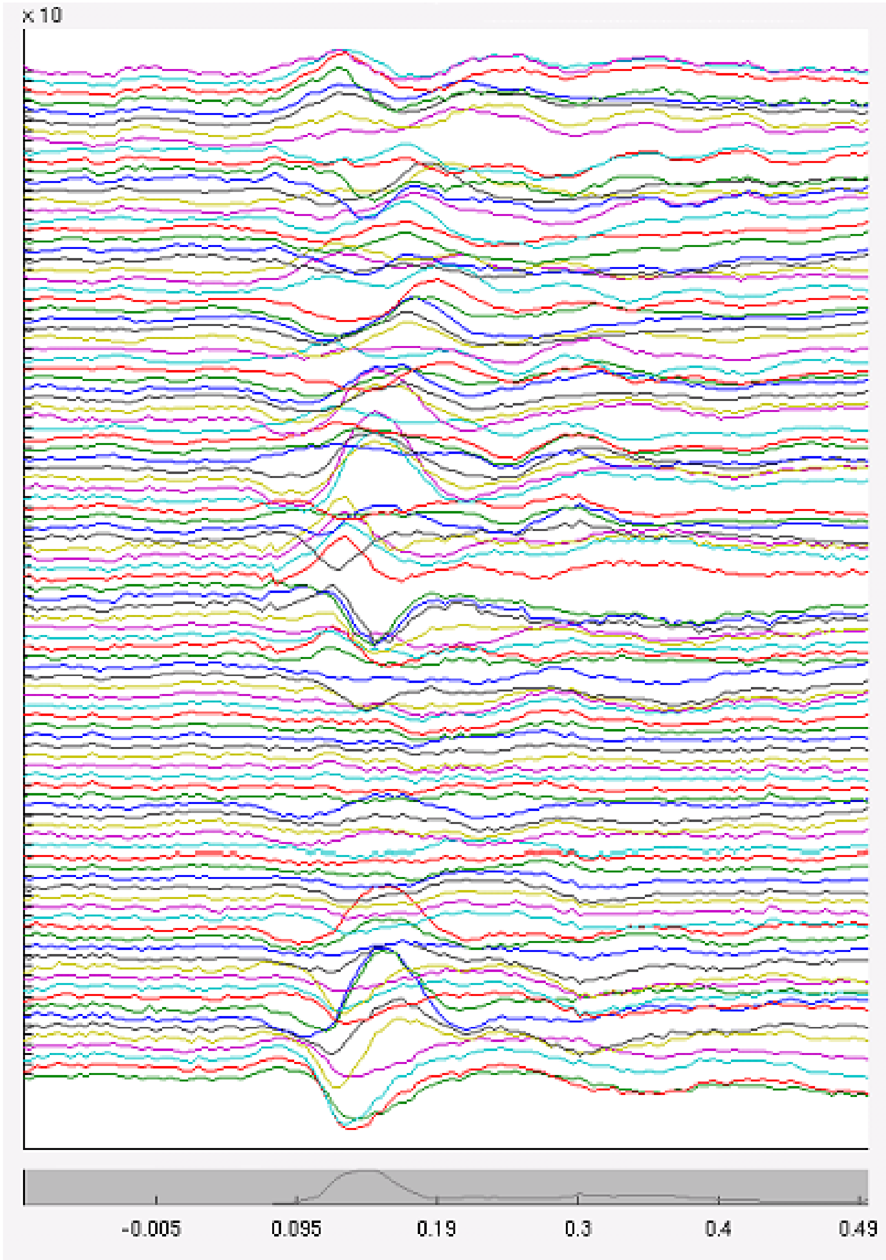
When/Where is the effect reliable?





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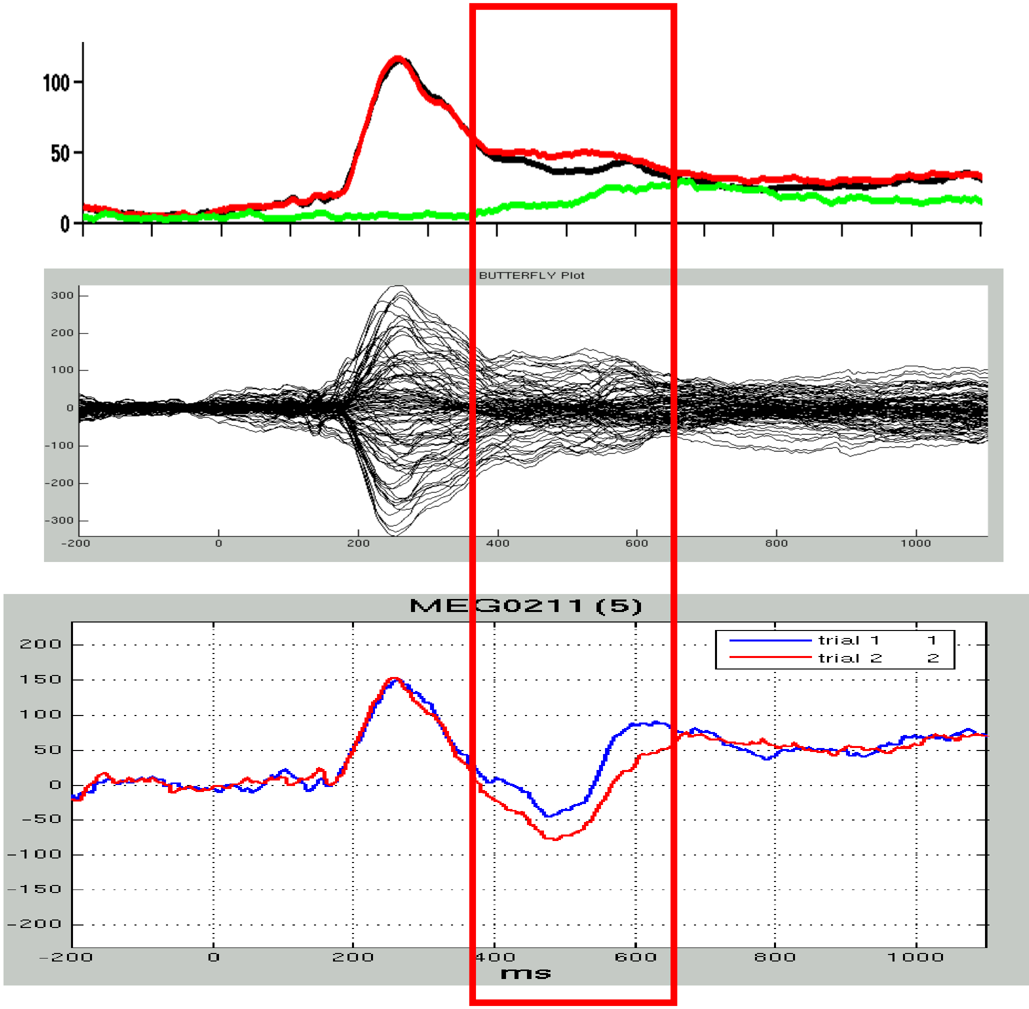
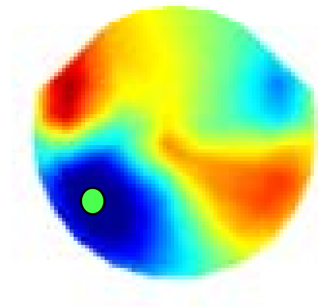
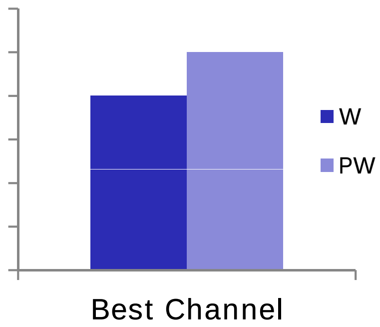






Common approach:

(1) View data, identify time-window containing effect, peak sensor(s)
(2) Extract and average data for conditions and subjects
(3) Compute statistics
* Circular if (1) performed on effect of interest
* OK if orthogonal effect or from literature

The Multiple Comparison Problem

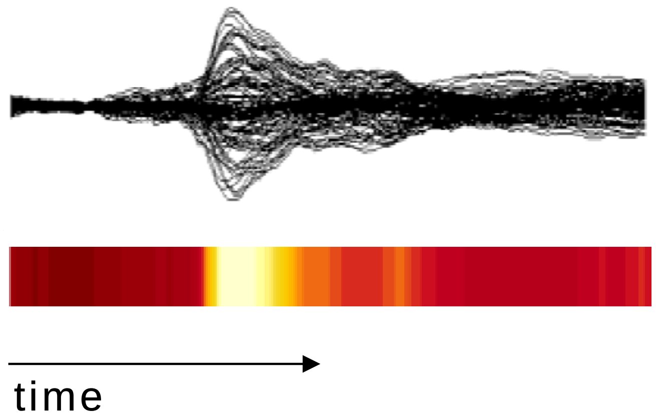
The Multiple Comparison Problem

- The more comparisons we conduct, the more Type I errors (false positives) we will make when the Null Hypothesis is true.

  * Must consider *Familywise* (vs. *per-comparison*) Error Rate

- Comparisons are often made *implicitly,* e.g., by viewing ("eye-balling") data before selecting a time-window or set of channels for statistical analysis.

-> **When** is there
an effect in time
e.g., GFP (1D)?



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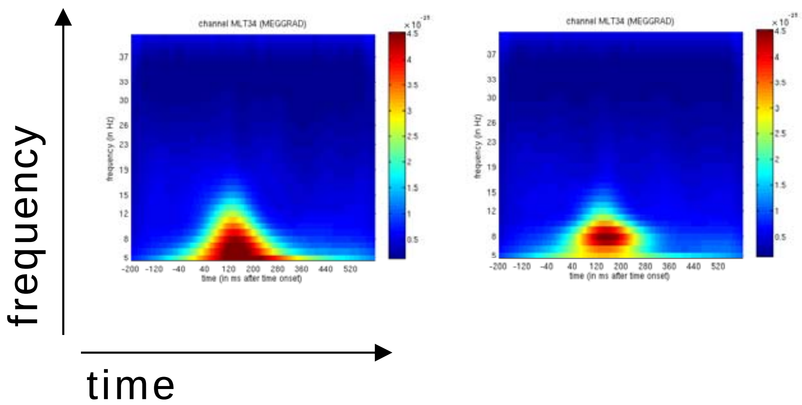
-> **When / at what frequency**

is there an effect

an effect in time/frequency

(2D)?



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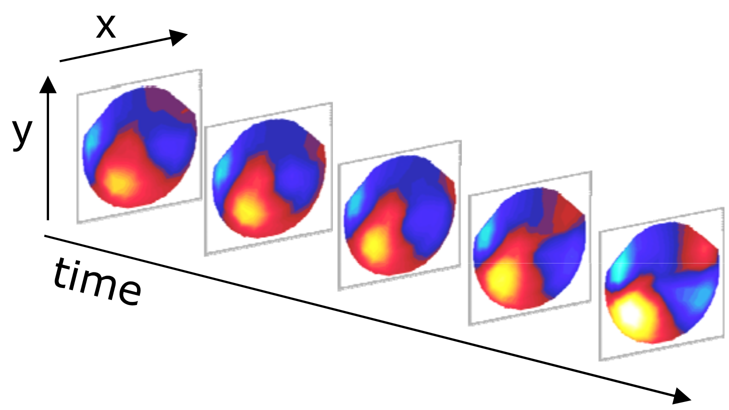
-> **When / where**

is there an effect

in sensor-topography

space/time (3D)?



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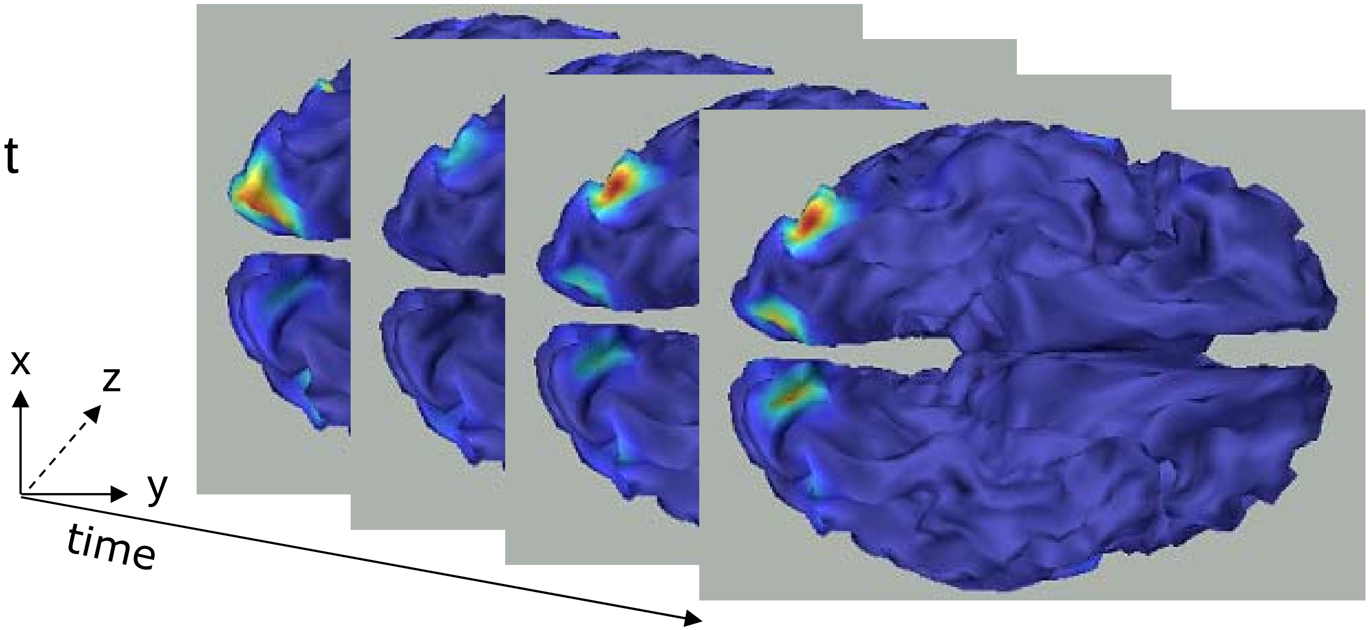
-> **When / where**
is there an effect
in source
space/time
(4-ish-D)?



Statistical Parametric Mapping (SPM)

- A mass-univariate statistical approach to inference regarding effects in space/time/frequency (using replications across trials or subjects).
- Data are converted into images, submitted to general linear model (GLM)
- Uses much of the same machinery employed in statistical analysis of fMRI data.

Random Field Theory (RFT) is a method for correcting for multiple statistical comparisons with N-dimensional spaces (for parametric statistics, e.g., Z-, T-, F- statistics).

* Correction depends on size of search volume
* Takes smoothness of images into account

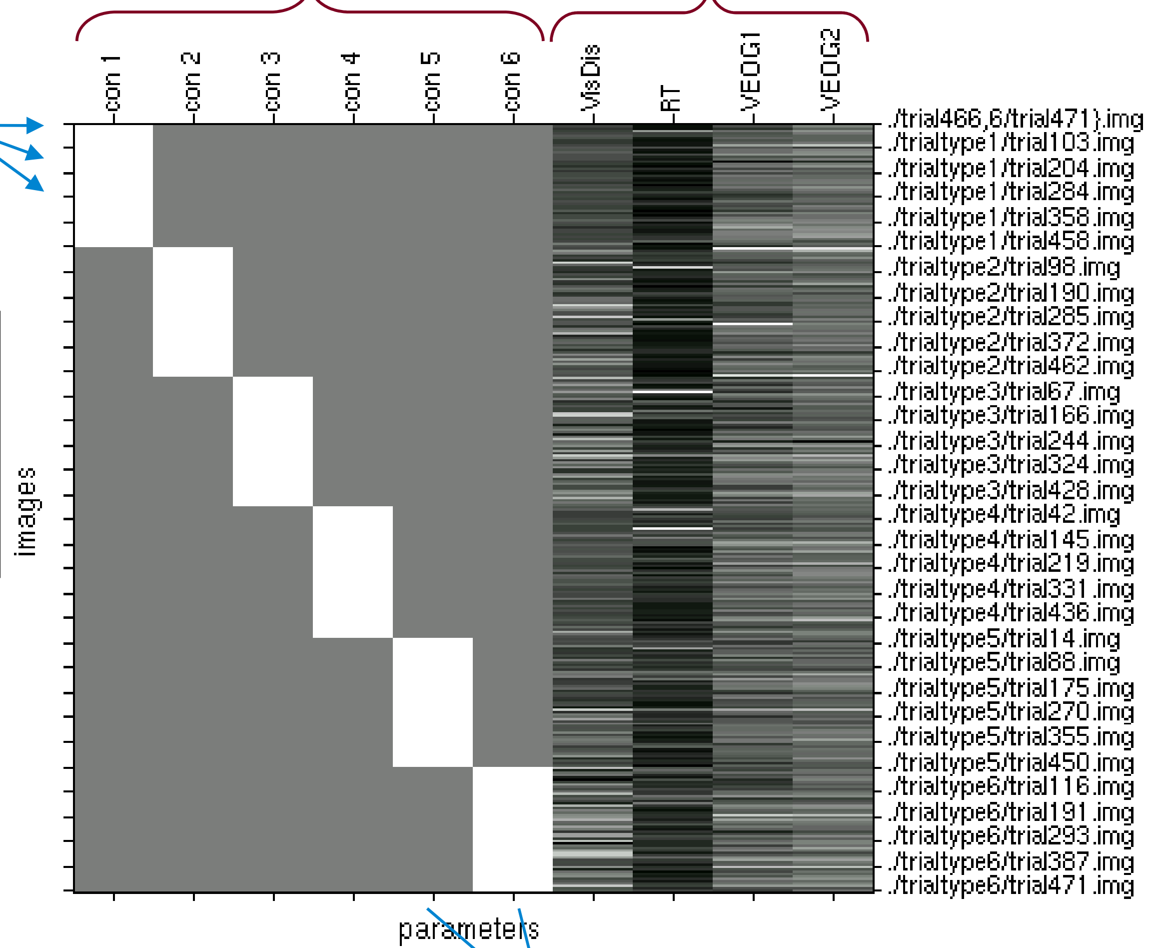
RFT: Worsley Et Al (1996). Human Brain Mapping, 4:58-73

GLM: Condition Effects **after** removing variance due to **confounds**

Each trial-type

Confounds

Each trial



W/in Subject
(1st-level) model
-> one image per trial
-> one covariate value per trial

Also: Group Analysis
(2nd-level)
-> one image per subject per condition
-> one covariate value per subject per condition

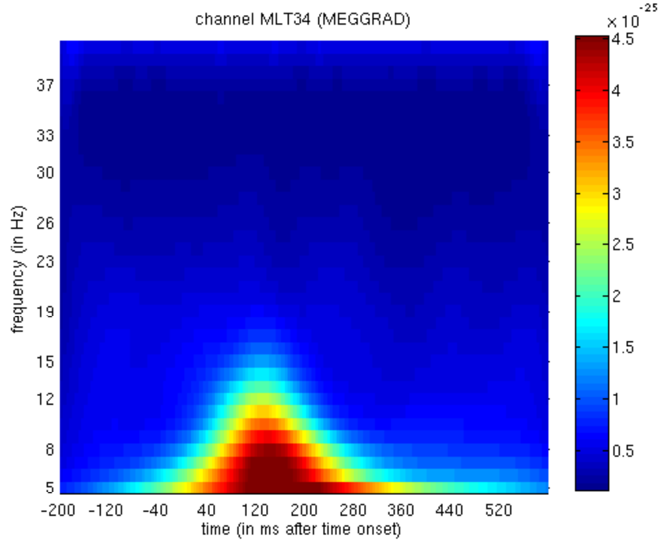
beta_00* image volumes reflect
(adjusted) condition effects

Henson et al., 2008, NImage

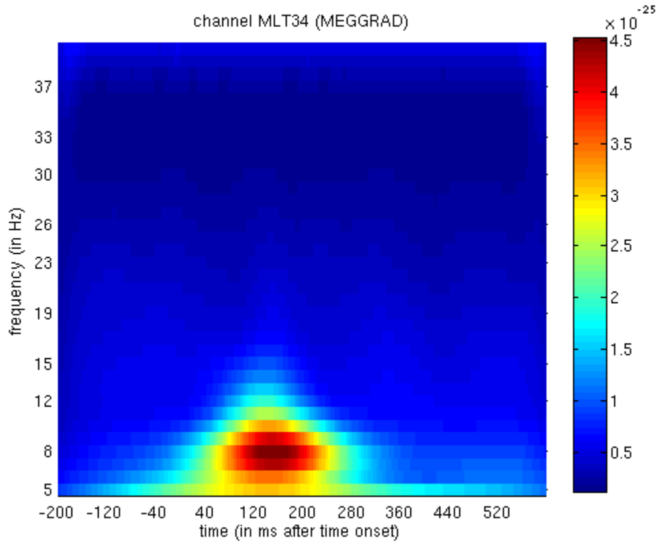
Sensor-space analyses

Where is an effect in **time-frequency space**?

Faces



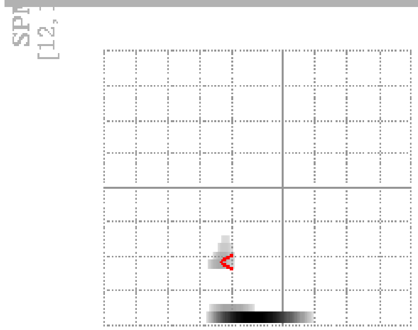
Scrambled



1 subject (1st-level analysis)
1 MEG channel

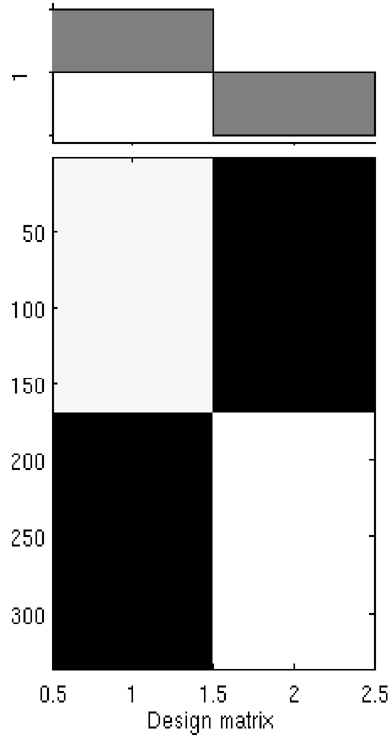
Morlet wavelet projection

1 t-x-f image per trial



SPM{T_{334}}

Faces > Scrambled



SPMresults: ./multimodal/MEG/TFstatsPow
Height threshold T = 3.736016 {p<0.05 (FWE)}
Extent threshold k = 0 voxels

Statistics: *p-values adjusted for search volume*

set-level		cluster-level				peak-level					Hz ms
p	c	$p_{FWE-corr}$	$q_{FDR-corr}$	k_E	p_{uncorr}	$p_{FWE-corr}$	$q_{FDR-corr}$	T	$(Z_{\equiv})$	p_{uncorr}	
0.001	2	0.000	0.006	79	0.003	0.000	0.002	5.40	5.28	0.000	5 185
		0.005	0.092	32	0.092	0.013	0.262	4.12	4.06	0.000	12 100

table shows 3 local maxima more than 8.0mm apart

Height threshold: T = 3.74, p = 0.000 (0.050)
Extent threshold: k = 0 voxels, p = 1.000 (0.050)
Expected voxels per cluster, <k> = 13.420
Expected number of clusters, <c> = 0.05
FWEp: 3.736, FDRp: 5.396, FWEc: 32, FDRc: 79

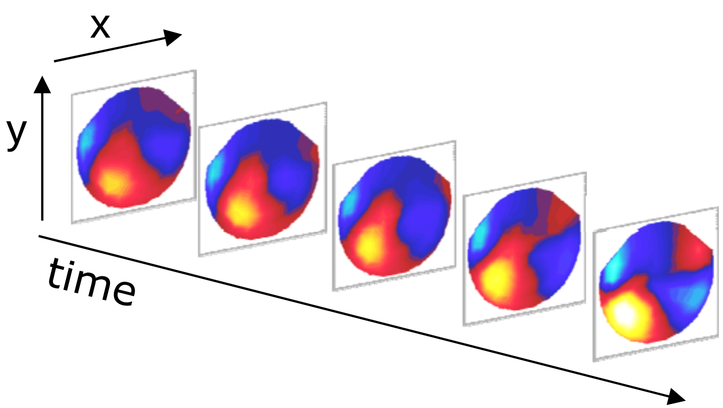
Degrees of freedom = [1.0, 334.0]
FWHM = 7.5 58.5 Hz ms ; 7.5 11.7 {voxels}
Volume: 28980 = 5796 voxels = 63.7 resels
Voxel size: 1.0 5.0 Hz ms ; (resel = 87.91 voxels)

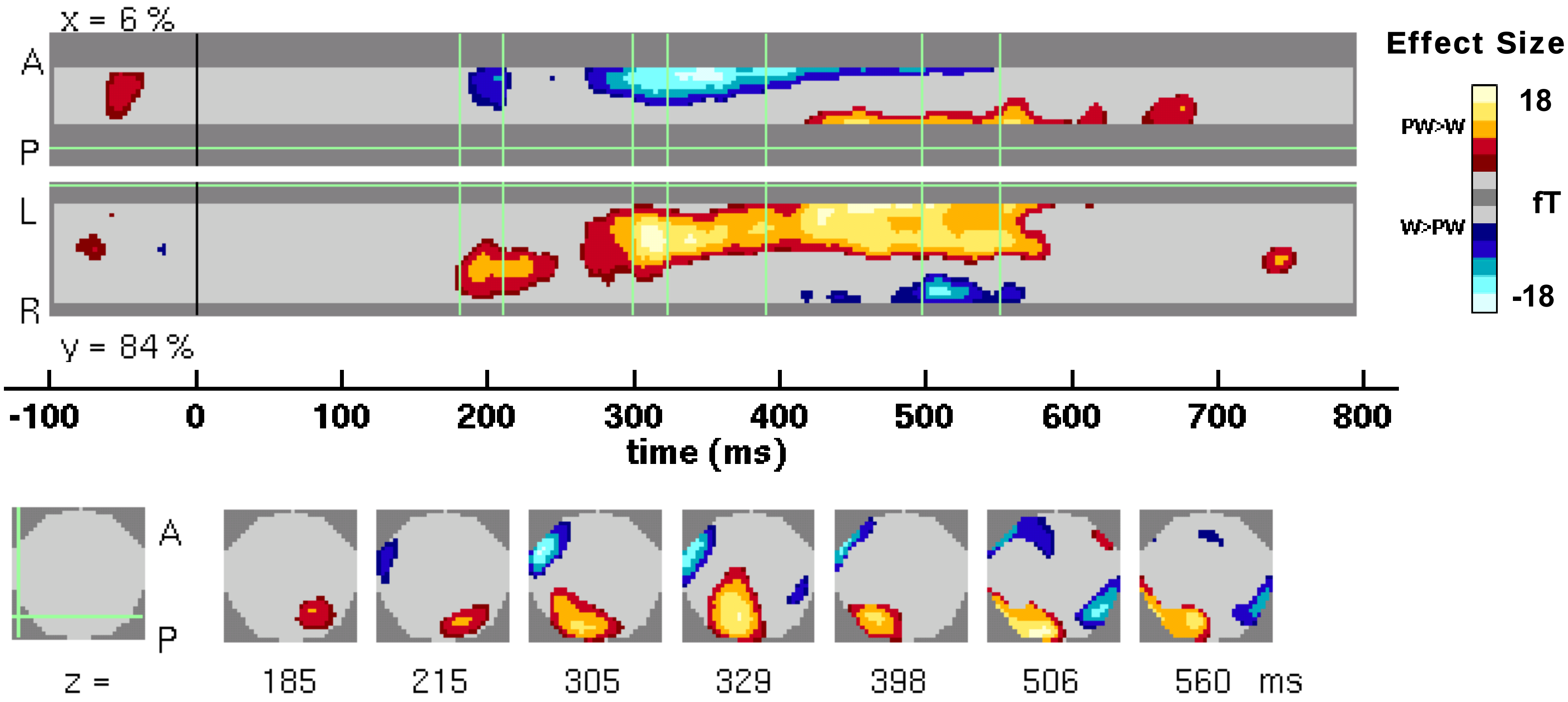
Kilner et al., 2005, Nsci Letters

CTF Multimodal Faces Dataset (Rik Henson)

Where is an effect in **sensor-time space**?

Analysis over subjects (2nd Level): Words vs. Pseudowords





Taylor & Henson (in review)

Source-space analyses

Where is an effect in **source space** (3D)?

STEPS:

Estimate evoked / induced energy (RMS) at each dipole for a certain time-frequency window of interest.

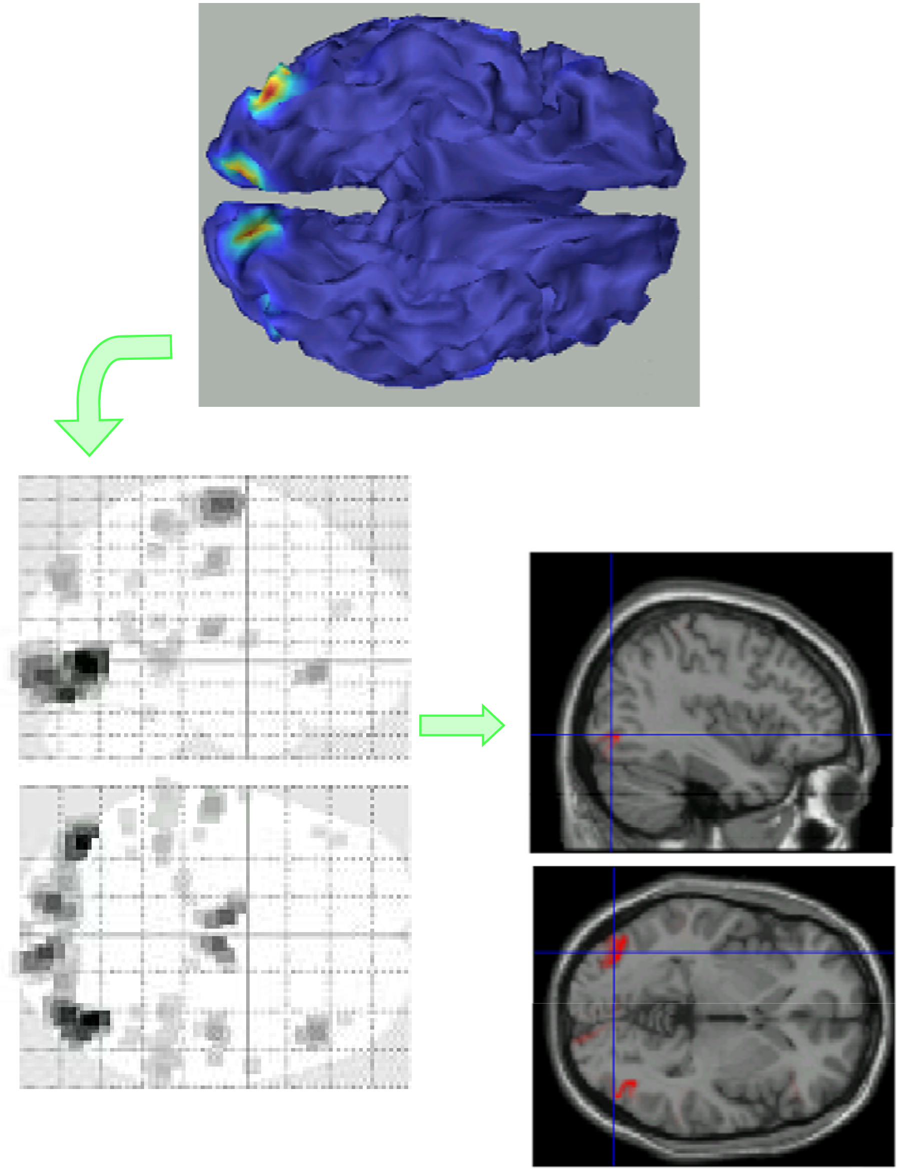
- e.g., 100-220ms, 8-18 Hz
- For each condition (Faces, Scrambled)
- For each sensor type OR fused modalities

Write data to 3D image

- in MNI space
- smooth along 2D surface

Smooth by 3D Gaussian

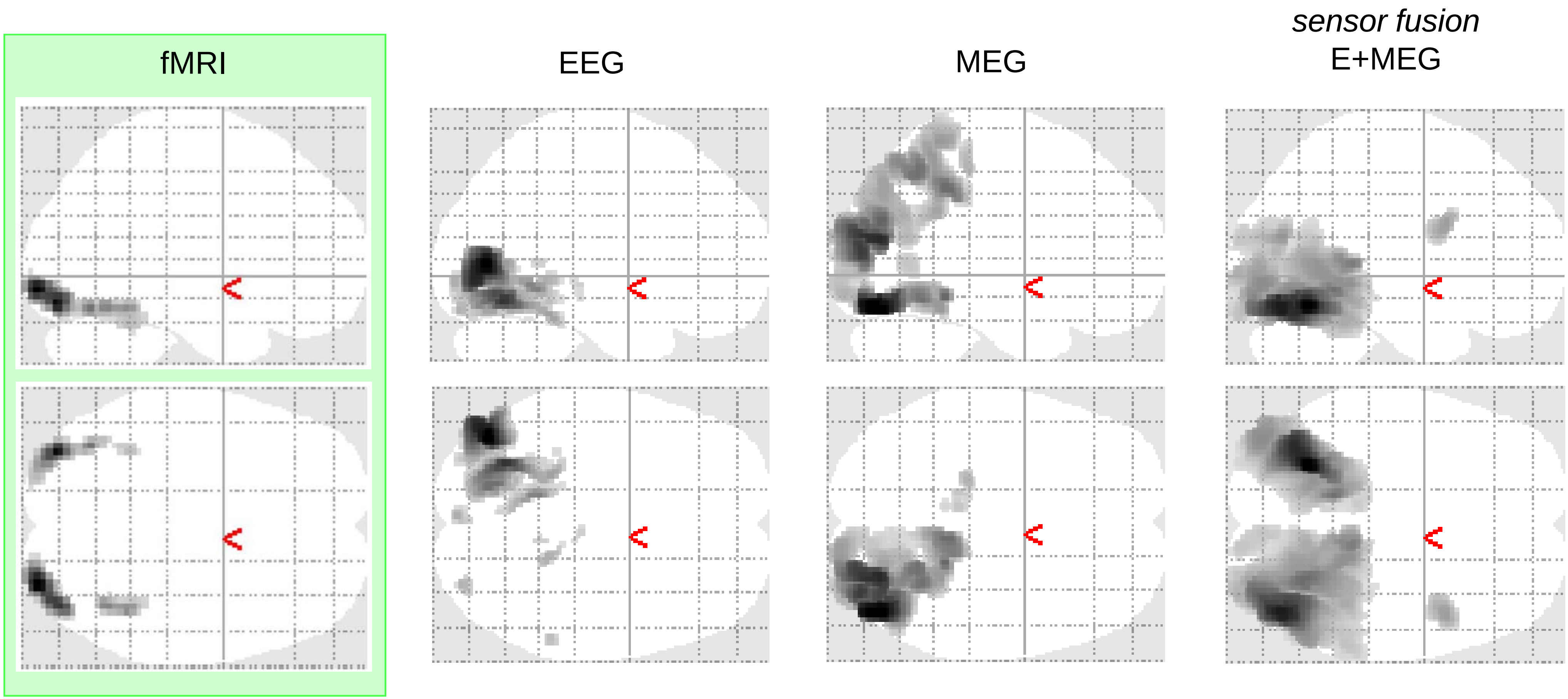
Submit to GLM



Henson et al., 2007, NImage

Where is an effect in **source space** (3D)?

RESULTS: Faces > Scrambled



Henson et al, 2011
Neuromag Faces

Where and When do effects **emerge / disappear** in source space (4-ish-D: time factorised)?

Condition x Time-window Interactions

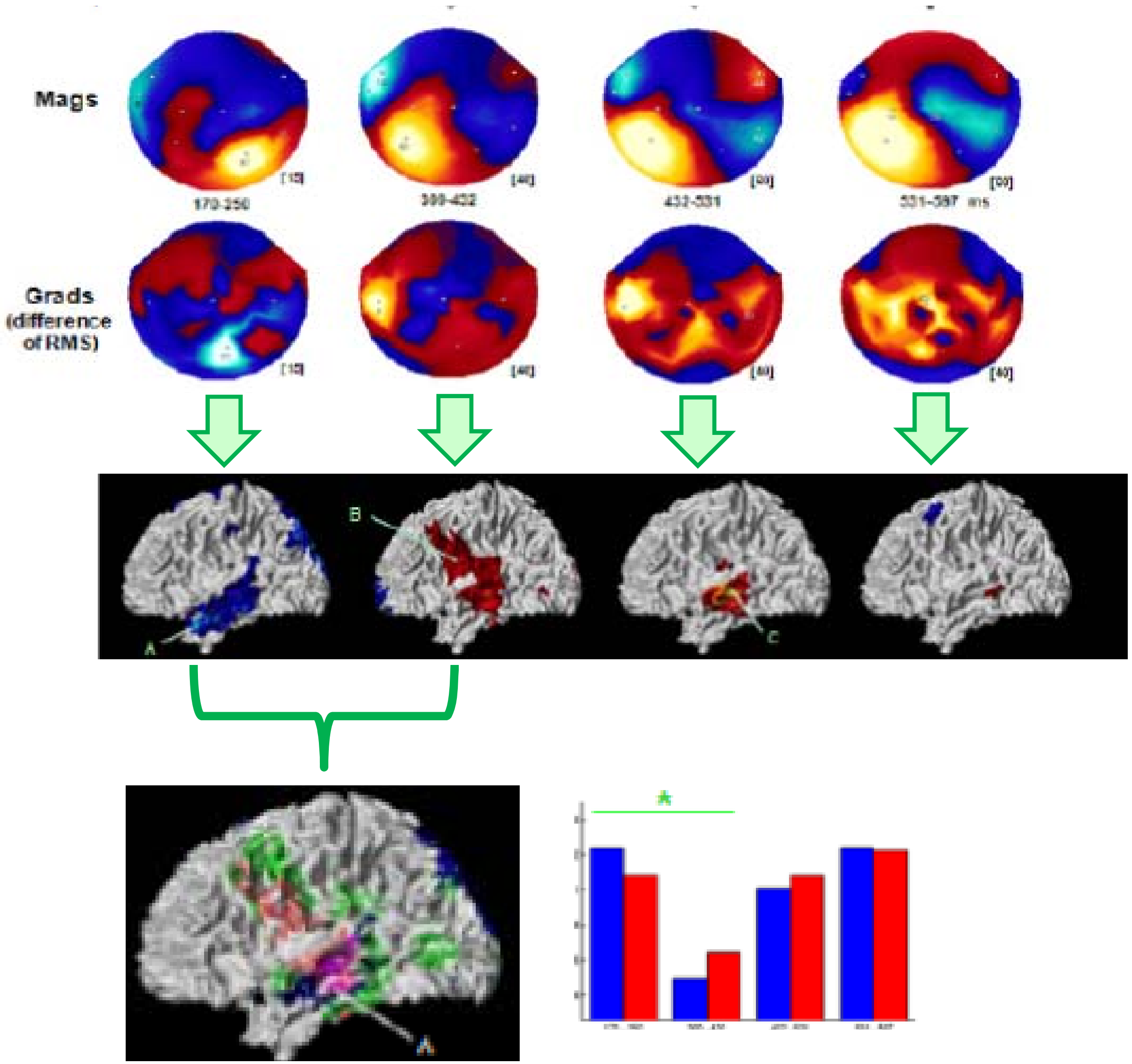
Factorising time allows you to *infer* (rather than simply *describe*) when effects emerge or disappear.

* estimate source energy in each sub-time-window

* submit to GLM with conditions & time-windows as factors

* Cond effects per t-win

* Cond x t-win interaction



Taylor & Henson, in review
Neuromag Lexical Decision

Alternative Approaches

Alternative Approaches

Non-Parametric Approach (SnPM)

Robust to non-Gaussian distributions

Less conservative than RFT when **dfs<20**

Caveats:

No idea of effect size (e.g., for power, future expts)

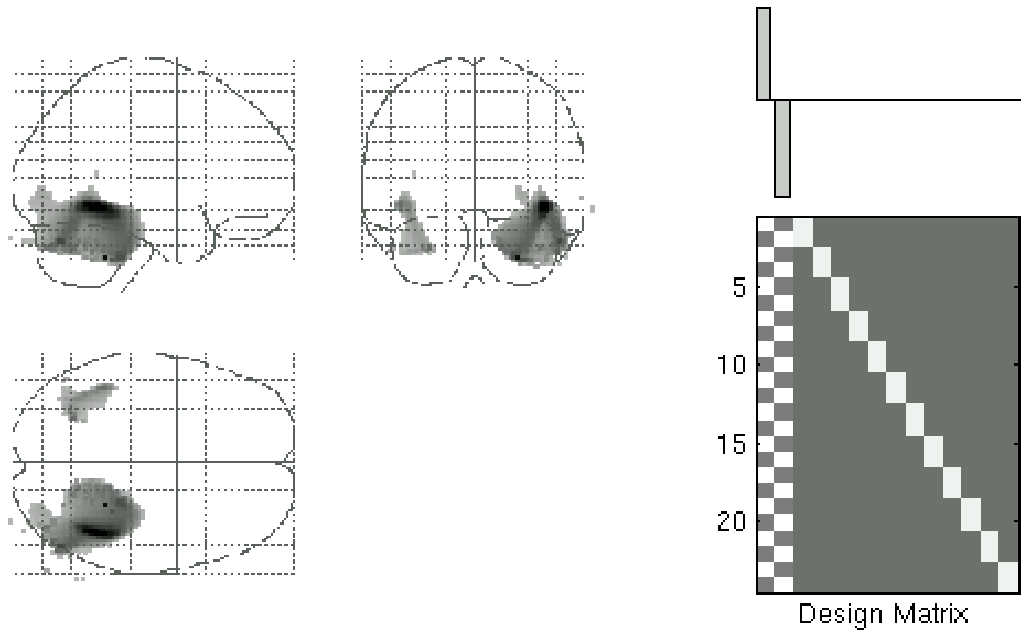
Exchangeability difficult for more complex designs

(Taylor & Henson, Biomag 2010)

SnPM Toolbox by Holmes & Nichols:
http://go.warwick.ac.uk/tenichols/software/snpm/

SnPM{T}

p<.05 FWE



P values & statistics: ./MEG_Group/SourceSPMs/Inv2/mags/SnPM

cluster-level	voxel-level				x,y,z mm		
k	$p_{FWE-corr}$	$p_{FDR-corr}$	T	p_{uncorr}			
4779	**0.0002**	**0.0034**	**12.03**	0.0002	**42**	**-52**	**-6**
	0.0002	0.0034	11.94	0.0002	44	-44	-8
	0.0002	0.0034	11.34	0.0002	26	-42	-38
619	**0.0032**	**0.0034**	**8.27**	0.0002	**-26**	**-62**	**-32**
	0.0032	0.0034	8.27	0.0002	-44	-44	-6
	0.0068	0.0034	7.55	0.0002	-40	-54	-6
1	**0.0139**	**0.0034**	**6.89**	0.0002	**50**	**-80**	**-30**
1	**0.0168**	**0.0034**	**6.63**	0.0002	**38**	**-34**	**-44**
1	**0.0212**	**0.0051**	**6.44**	0.0005	**58**	**-64**	**-32**

CTF Multimodal Faces

Alternative Approaches

Posterior Probability Maps (PPMs)

Bayesian Inference

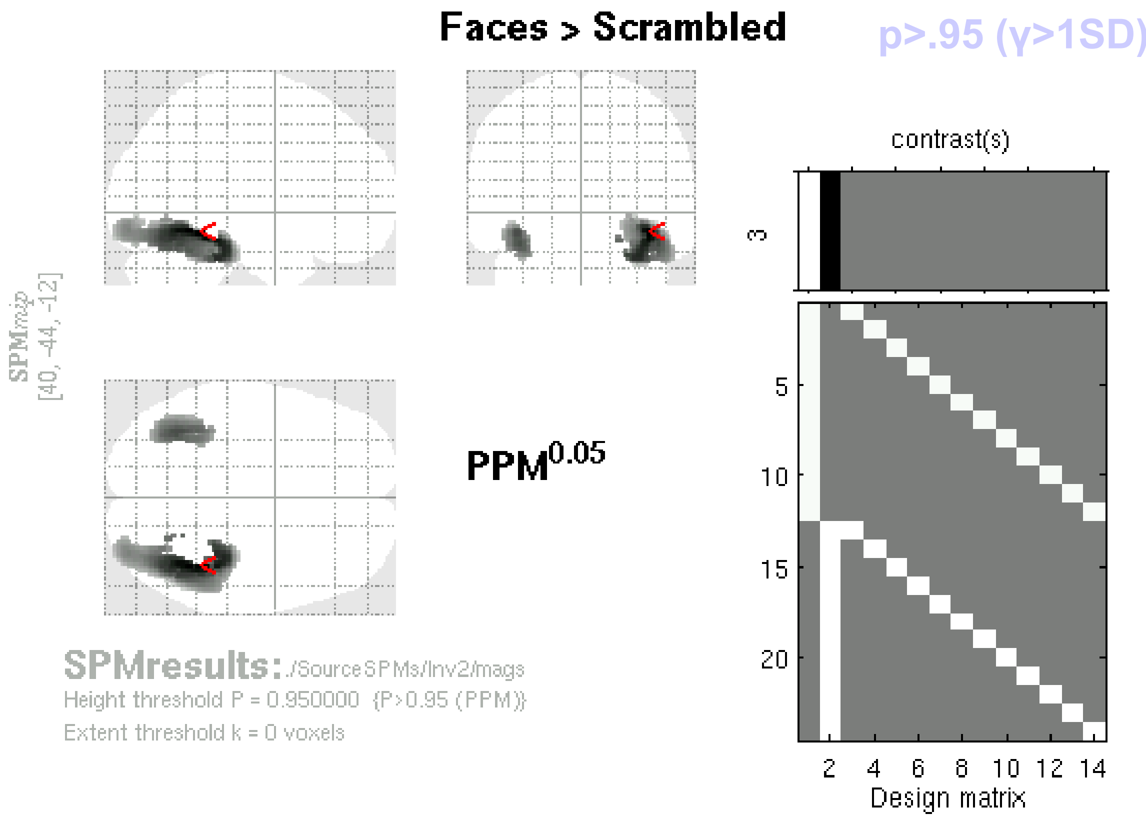
No need for RFT (**no MCP**)

Threshold on posterior probabilty of an effect greater than some size

Can show **effect size** after thresholding

Caveats:

Assume Gaussian distribution (e.g., of mean over voxels)



Statistics: ***Posterior Probabilities***

set-level c	cluster-level k_E	peak-level P	peak-level $(Z_{\equiv})$	mm mm mm
6	1239	0.18	-0.92	40 -44 -12
		0.17	-0.95	38 -56 -10
		0.17	-0.96	40 -34 -16
	395	0.14	-1.08	-38 -56 -12
		0.13	-1.13	-38 -46 -14
		0.12	-1.16	-34 -46 -22
	1	0.12	-1.15	22 -54 -16
	2	0.12	-1.15	24 -62 -16
	1	0.12	-1.20	22 -60 -14
	4	0.11	-1.23	30 -62 -4

CTF Multimodal Faces

-- The end --

- Thanks for listening

- Acknowledgements:
  - Rik Henson (MRC CBU)
  - Dan Wakeman (MRC CBU / now at MGH)
  - Vladimir, Karl, and the FIL Methods Group

- More info:
  - **http://imaging.mrc-cbu.cam.ac.uk/meg (wiki)**

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