Statistical Analysis of Sensor Data

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Overview

1 Introduction

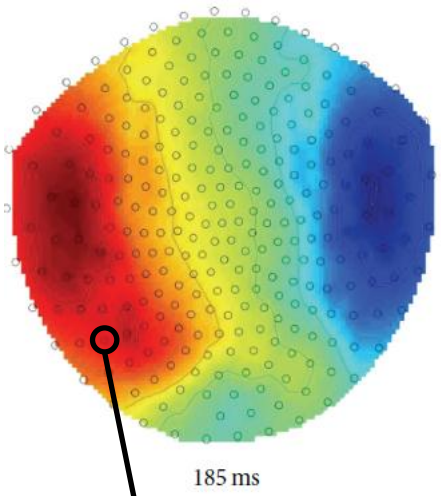
2 Within-subject analysis

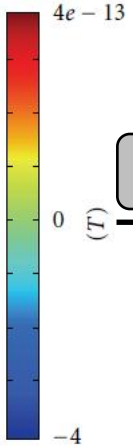
3 Between-subject analysis

4 Generic issues

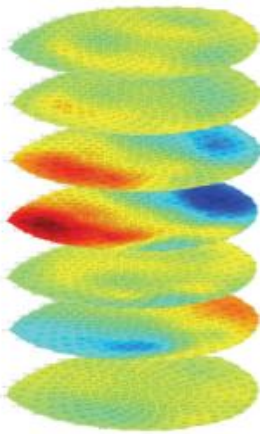
Overview

Sensor space

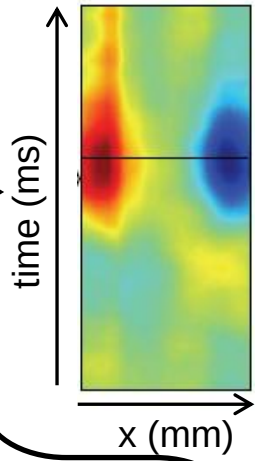


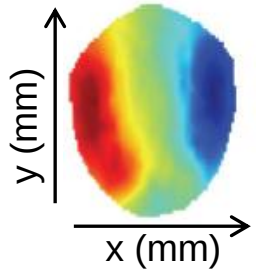


stack

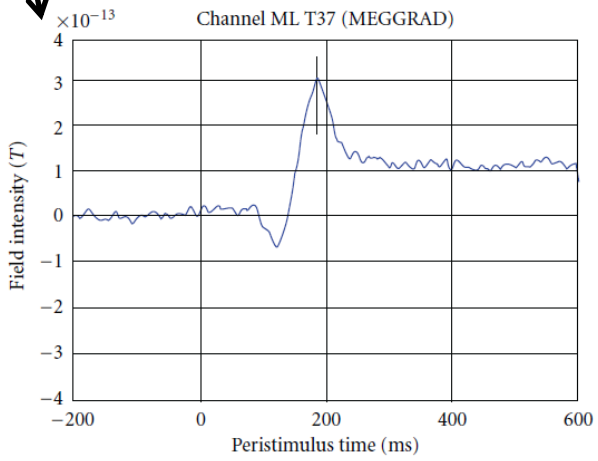


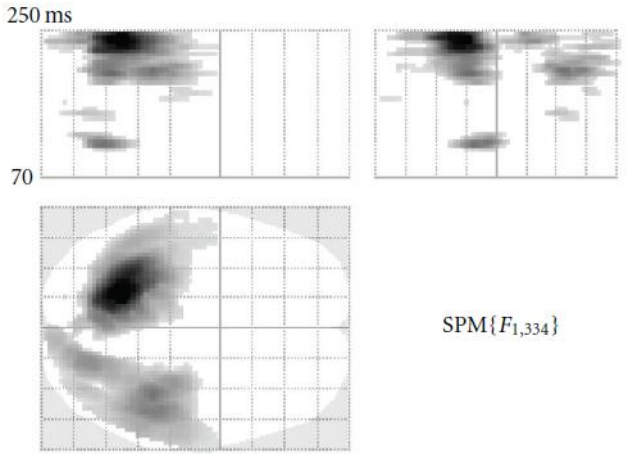
interpolate





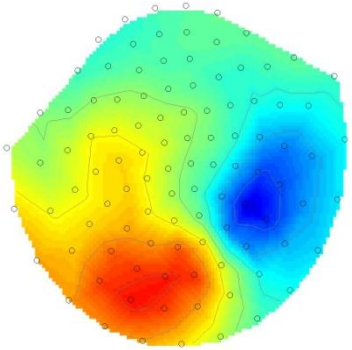
Statistical Parametric Map



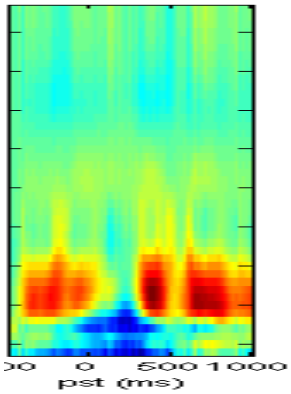


Litvak et al. (2011), Comp Intell and Neurosc

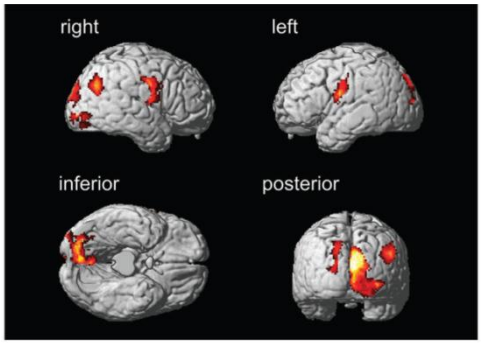
Type of maps



2D topography



Time-Frequency



Source reconstructed

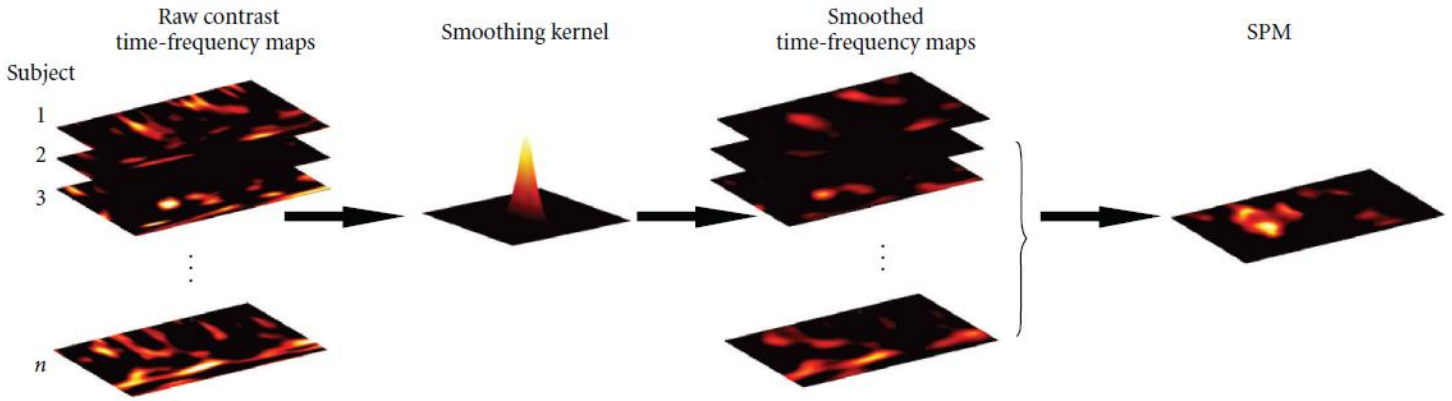
Time

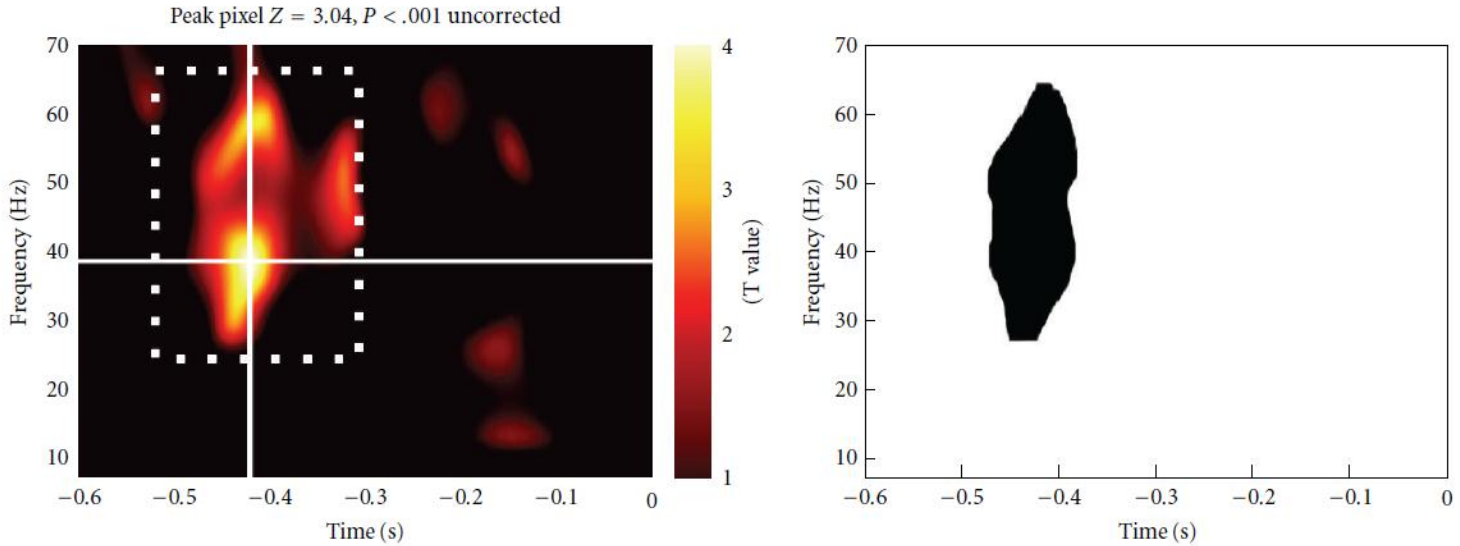
Location

Time

Experimental design (conditions and repetitions, e.g. subjects)

Multiple comparisons





Kilner et al. (2005), Neurosc Letters

Multimodal face study

MEG & EEG (CTF)

128 EEG
275 MEG

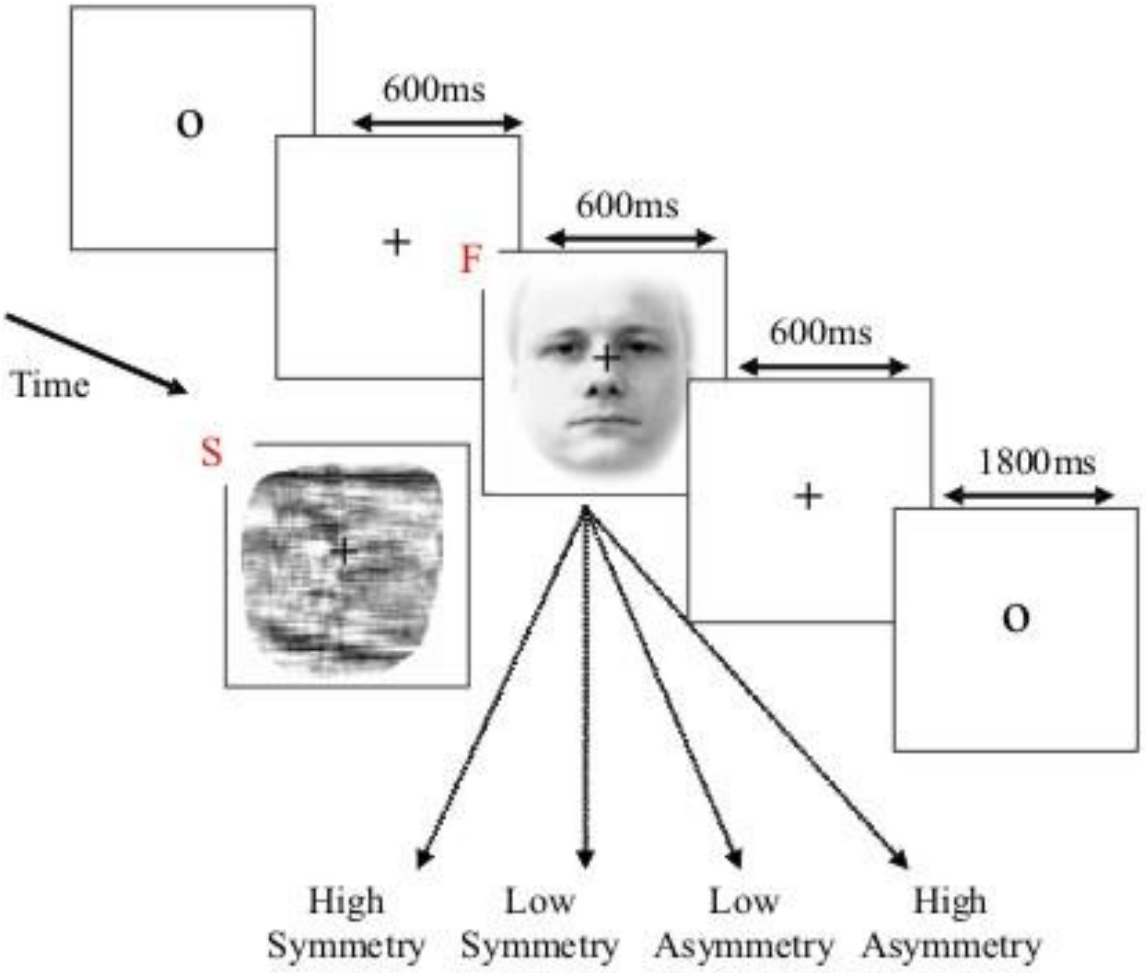
(fMRI, sMRI)

Data

N=12 subjects

2 sessions

per session
~160 face trials
~160 scrambled trials

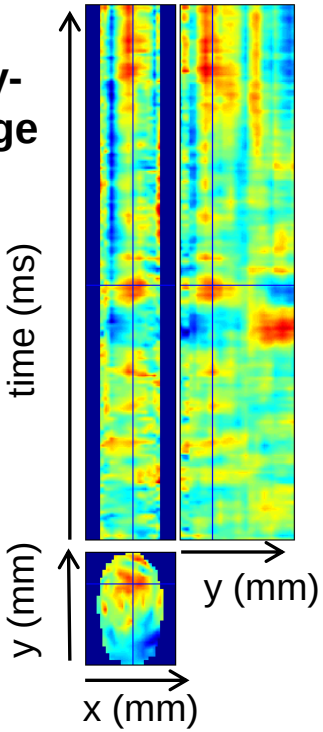


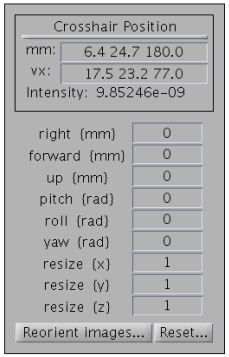
Henson et al. (2009); SPM8 Manual: Chapter 37

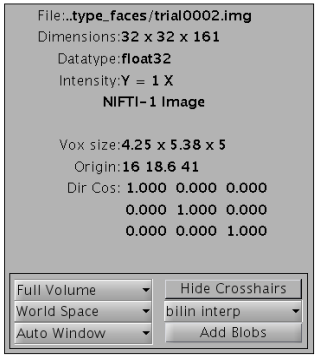
Overview

Within subject: Sensor-Time (3D)

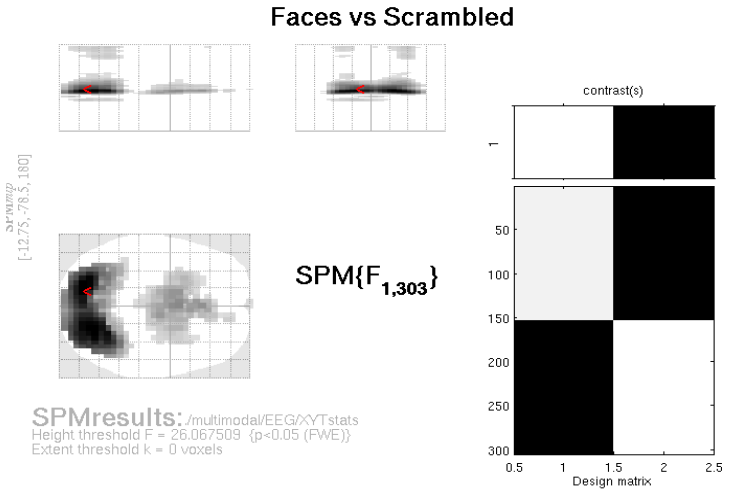
Topography-x-Time Image (EEG)







Stats (F): Faces vs Scrambled (single subject, over trials)



Statistics: *p-values adjusted for search volume*

set-level		cluster-level				peak-level					mm mm ms
p	c	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	k_E	p_{uncorr}	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	F	(Z_e)	p_{uncorr}	
0.000	**18**			**4025**		**0.000**	**0.000**	**233.47**	**Inf**	**0.000**	**-13 -78 180**
						0.000	0.000	232.38	Inf	0.000	21 -68 180
						0.000	0.000	217.35	Inf	0.000	26 -57 185
				1458		**0.000**	**0.000**	**102.32**	**Inf**	**0.000**	**0 8 180**
						0.000	0.000	98.19	Inf	0.000	0 29 185
						0.000	0.000	92.29	Inf	0.000	-13 8 185
				32		**0.000**	**0.000**	**57.89**	**7.18**	**0.000**	**4 -89 125**
				544		**0.000**	**0.000**	**51.37**	**6.78**	**0.000**	**34 -57 590**
						0.000	0.000	48.66	6.61	0.000	34 -68 585
						0.000	0.000	47.36	6.52	0.000	34 -57 505
				150		**0.000**	**0.000**	**49.74**	**6.68**	**0.000**	**-13 -78 100**
						0.000	0.001	45.23	6.38	0.000	-13 -57 100
						0.000	0.002	43.15	6.24	0.000	-8 -78 90
				130		**0.000**	**0.002**	**43.09**	**6.23**	**0.000**	**-26 -78 590**
						0.000	0.002	42.79	6.21	0.000	-26 -78 600
						0.000	0.005	39.63	5.99	0.000	-26 -78 575
				55		**0.001**	**0.028**	**35.32**	**5.66**	**0.000**	**-21 -68 335**
						0.001	0.037	34.48	5.59	0.000	-21 -68 320
						0.002	0.050	33.64	5.52	0.000	-21 -73 305
				7		**0.004**	**0.112**	**31.69**	**5.36**	**0.000**	**-26 -73 505**
				9		**0.006**	**0.154**	**30.88**	**5.29**	**0.000**	**30 -57 335**

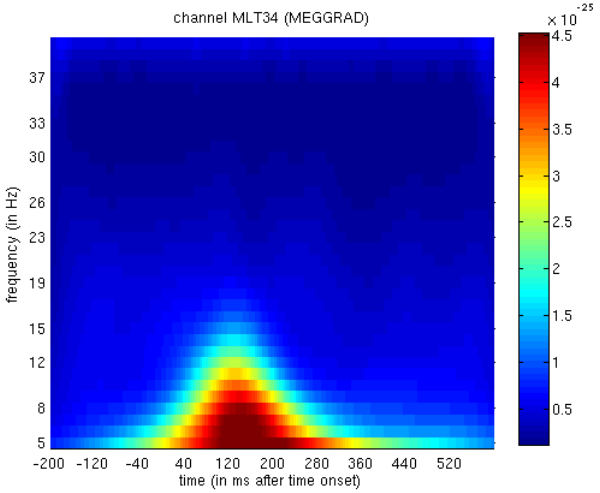
table shows 3 local maxima more than 8.0mm apart

Height threshold: F = 26.07, p = 0.000 (0.050)
Extent threshold: k = 0 voxels, p = 1.000 (0.050)
Expected voxels per cluster, <k> = 1.169
Expected number of clusters, <c> = 0.05
FWEp: 26.068, FDRp: 33.737

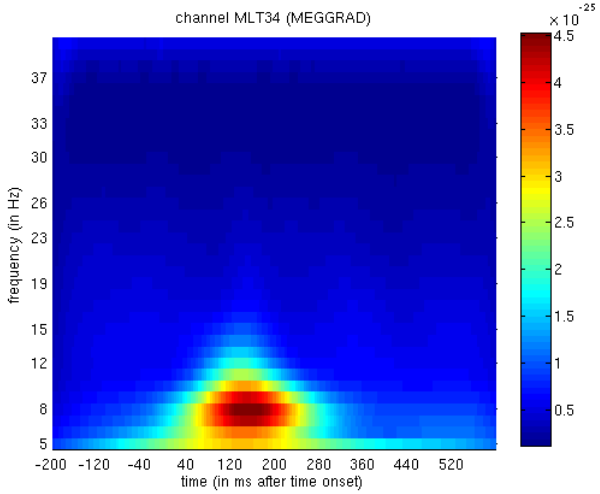
Degrees of freedom = [1.0, 303.0]
FWHM = 15.4 20.0 16.8 mm mm ms; 3.6 3.7 3.4 {voxels}
Volume: 11603597 = 101591 voxels = 2034.2 resels
Voxel size: 4.2 5.4 5.0 mm mm ms; (resel = 45.31 voxels)
Page 1

Within-subject: Time-Frequency

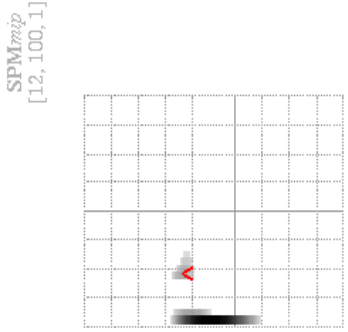
Faces



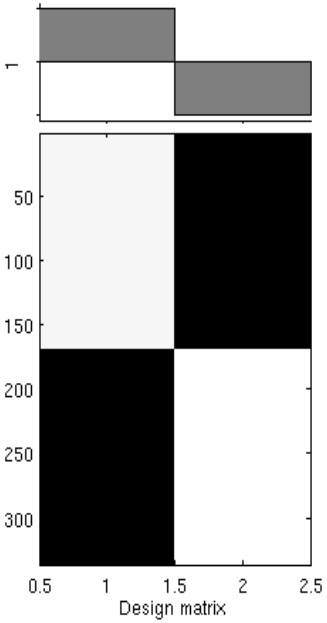
Scrambled



Difference **Faces > Scrambled**



$SPM\{T_{334}\}$



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*

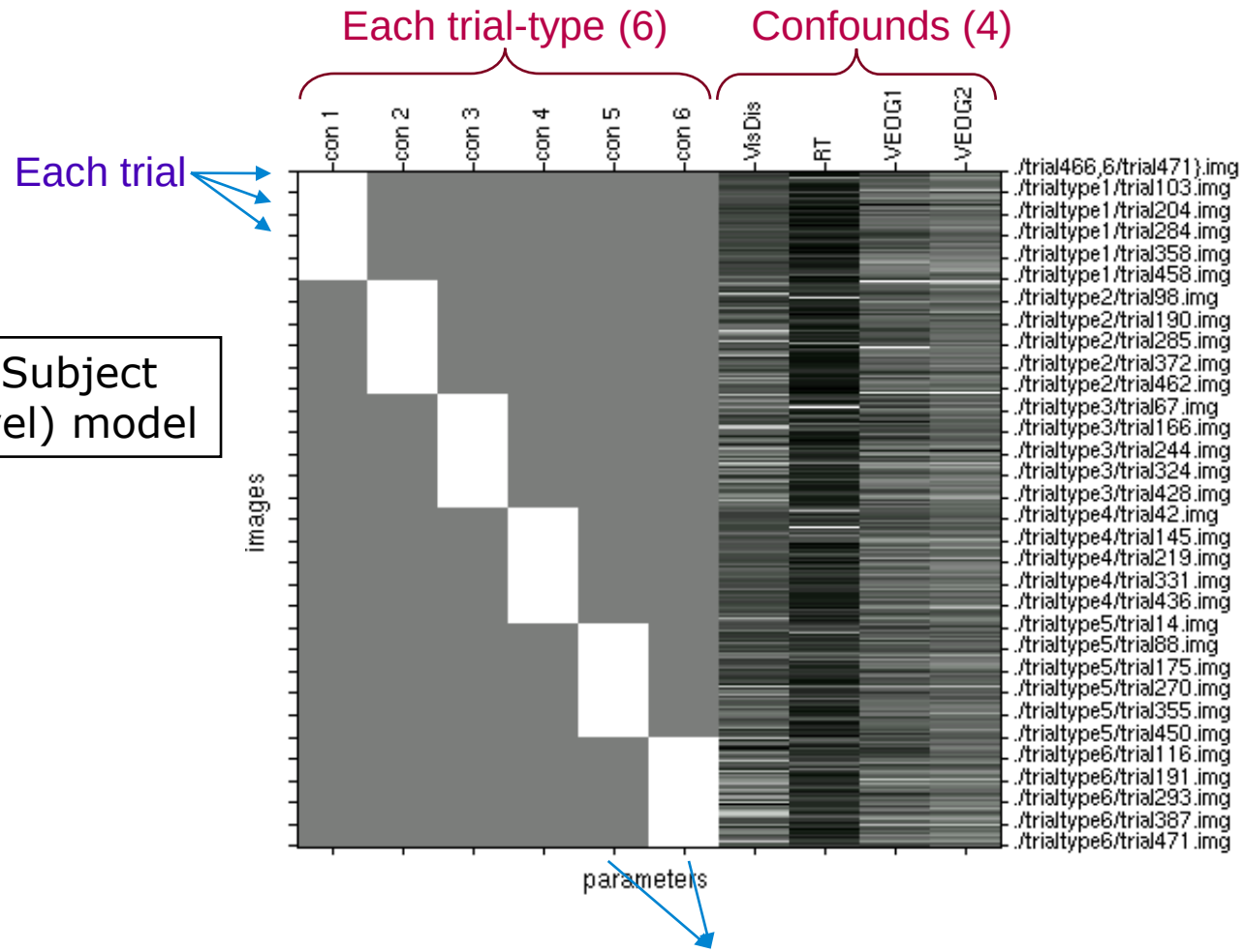
set-level		cluster-level				peak-level					Hz ms
p	c	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	k_E	p_{uncorr}	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	T	$(Z_{\equiv})$	p_{uncorr}	
0.001	2	0.000	0.006	79	0.003	0.000	0.002	5.40	5.28	0.000	5 185
		0.005	0.092	32	0.092	0.013	0.262	4.12	4.06	0.000	12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

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)

Removing variance due to confounds



Within Subject (1st-level) model

beta_00* images reflect mean (adjusted) 3D topo-time volume for each condition

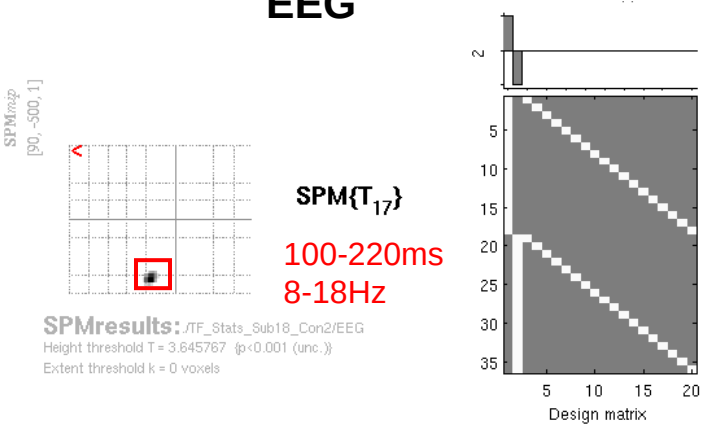
Henson et al. (2008), NeuroImage

Overview

Between subjects: Time-Frequency

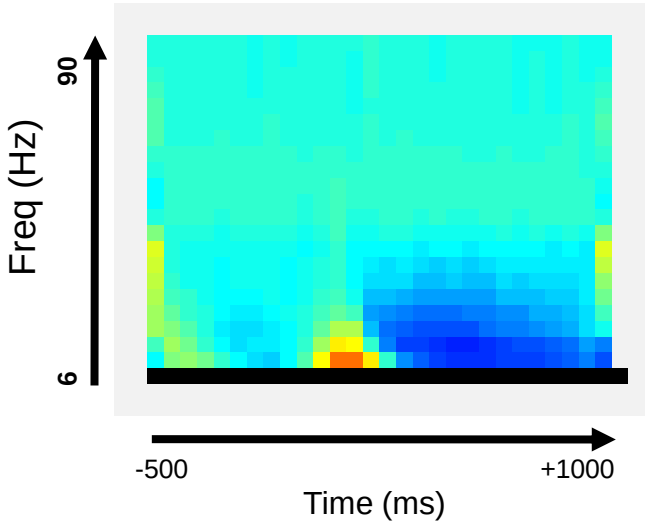
Faces > Scrambled

EEG

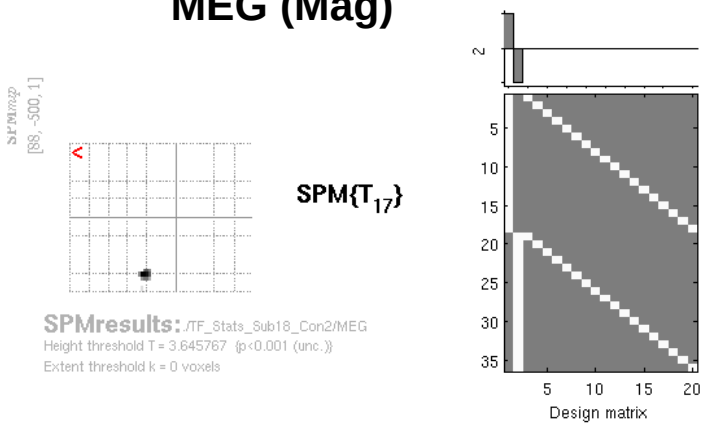


Statistics: *p-values adjusted for search volume*

	cluster-level				peak-level					Hz ms	
	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	k_E	p_{uncorr}	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	T	$(Z_{\equiv})$	p_{uncorr}		
	0.016	0.023	19	0.023	0.051	0.076	5.15	3.94	0.000	12	160

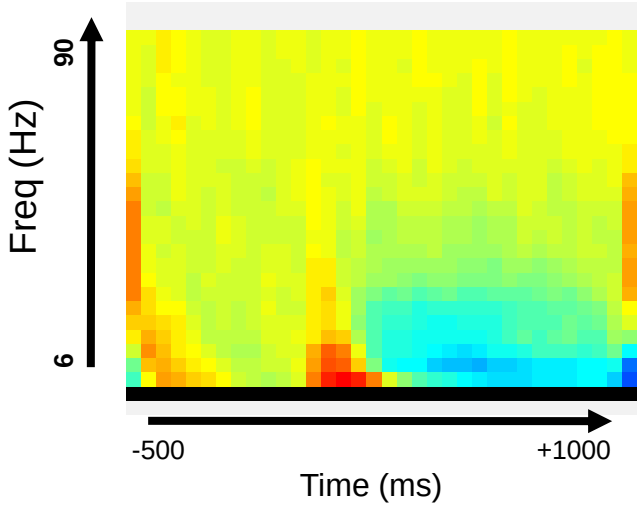


MEG (Mag)

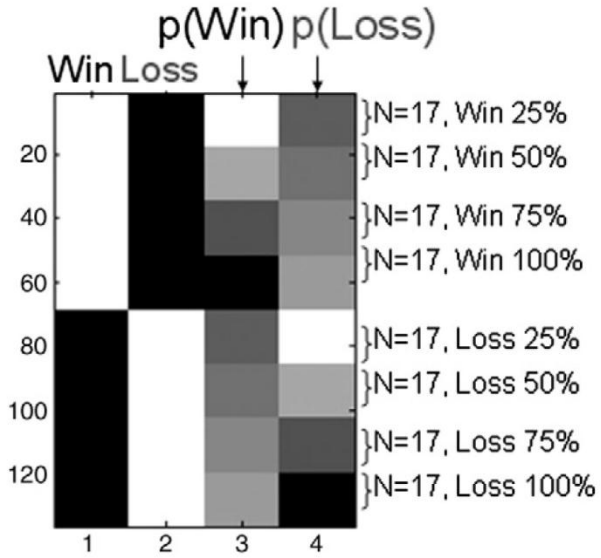


Statistics: *p-values adjusted for search volume*

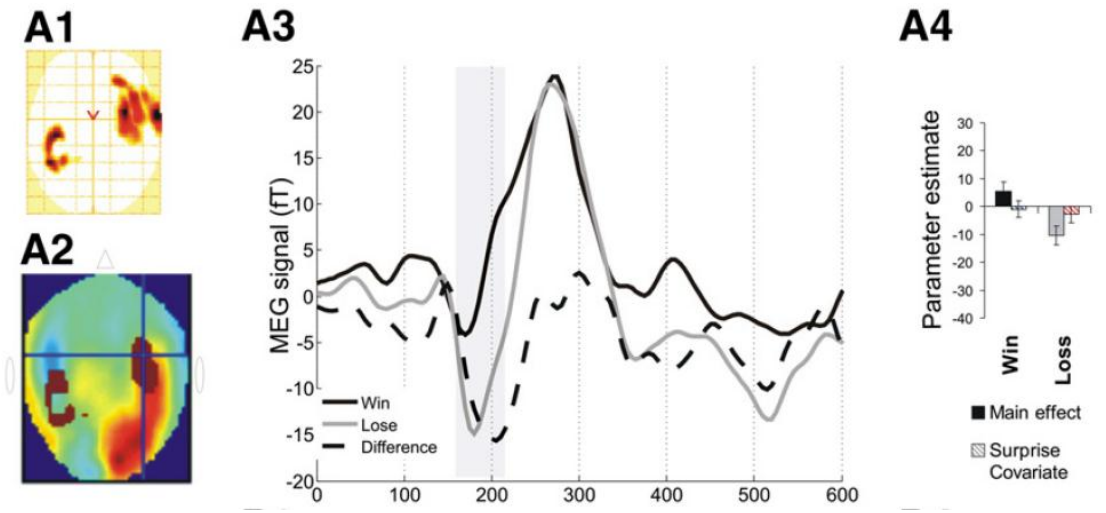
	set-level		cluster-level				peak-level					Hz ms	
	p	c	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	k_E	p_{uncorr}	$p_{FWE\text{-}corr}$	$q_{FDR\text{-}corr}$	T	$(Z_{\equiv})$	p_{uncorr}		
	0.161	2	0.059	0.169	12	0.085	0.082	0.240	4.88	3.81	0.000	14	80
			0.441	0.814	1	0.814	0.507	0.991	3.65	3.09	0.001	6	80



Parametric design at group level (MEG)



2nd level design matrix

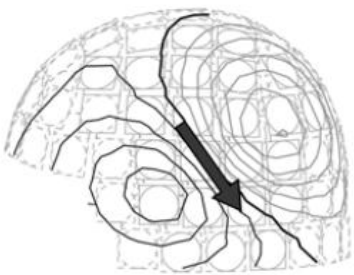


SPM, grand mean, and effect size

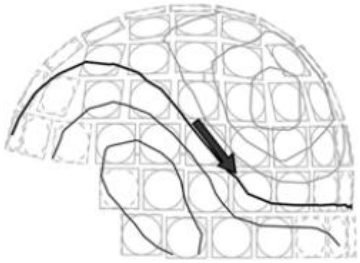
Talmi et al. (2012), NeuroImage

MEG: Alignment of sensor data

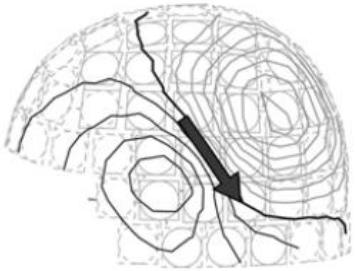
Subjects can move or be aligned differently with respect to sensors



stable



moving



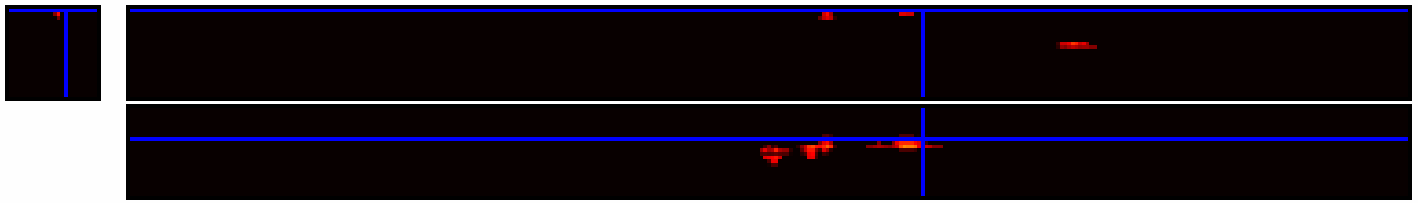
corrected

Taulu et al. (2005), IEEE Trans on Signal Processing; Software MaxFilter (Elekta NeuroMag)

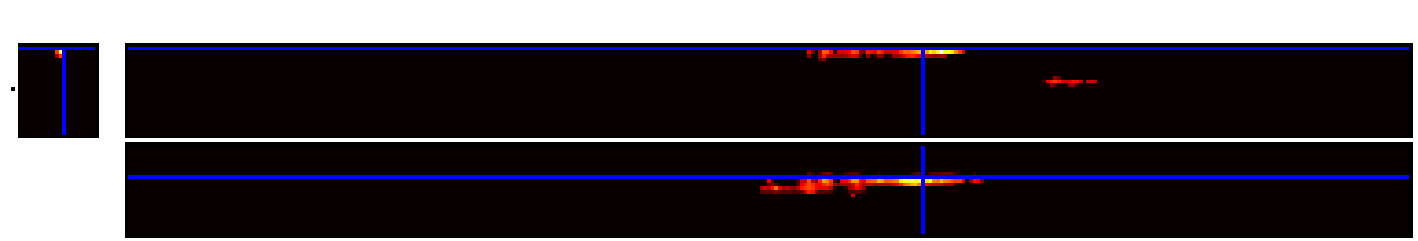
MEG between-subjects

Analysis over subjects (2nd Level)
NOTE for MEG: Complicated by variability in head-position
SOLUTION: Virtual transformation to same position in sessions, subjects

Without transformation to Device Space



With transformation to Device Space



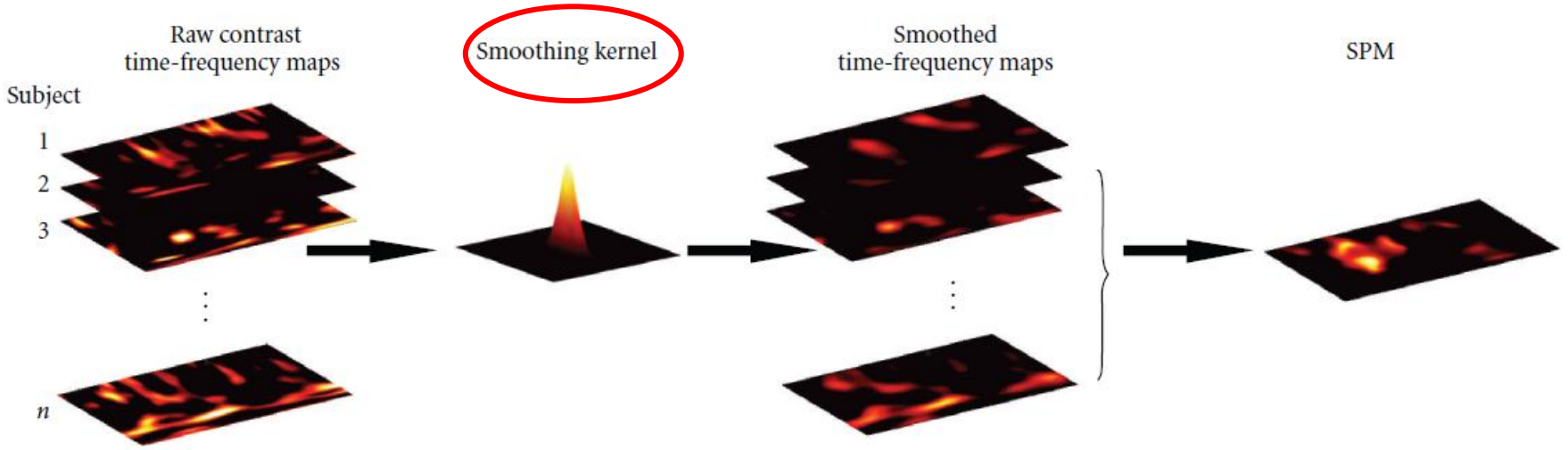
Stats over 18 subjects, planar gradiometers

Improved with transform: more blobs, larger T values

Taylor & Henson (2008) Biomag; Taulu et al. (2005), IEEE Trans on Sig Process

Overview

Smoothing



- Matched filter theorem: Different data needs different kernels
- Smoothing helps aligning the data
- Random field theory assumptions
- Evoked responses:
  - Some studies have used Gaussian kernel with FWHM of 8 - 10 mm in space (after transforming in voxel-space), and 8 - 10 ms in time
  - Note: Some temporal smoothness already because of lowpass filter

Litvak et al. (2011), Comp Intell and Neurosc

Significant results?

Potentially useful in practice:

- Use strong prior hypothesis
  - reduces search volume (lower corrected p-values)
  - can be more compelling
  - use small volume correction
  - equivalent to fMRI: use uncorrected p-values in case of hypothesis
- Functional localizer
  - For example: Localize ROIs for response to faces in each subject
- EEG/MEG: More subjects necessary than for equivalent fMRI studies?

References

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Talmi D, Fuentemilla L, Litvak V, Duzel E, Dolan RJ (2012). An MEG signature corresponding to an axiomatic model of reward prediction error. NeuroImage 59: 635-645

Taulu S, Simola J, Kajola M (2005). Applications of the Signal Space Separation Method. IEEE Transaction on Signal Processing, 53: 3359-3372

Thank you

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