PSYCHOPHYSIOLOGICAL INTERACTIONS

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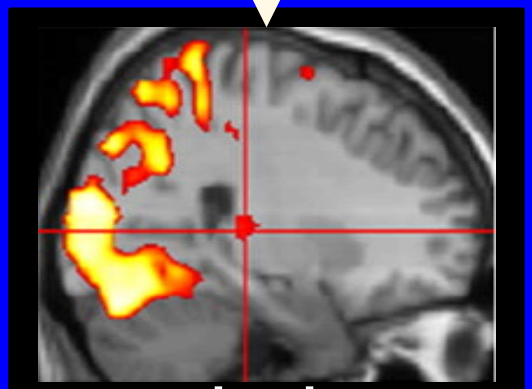
Systems analysis in functional neuroimaging

Functional specialization

- Analyses of regionally specific effects
- Which regions are specialized for a particular task?)
- Univariate analysis



Standard SPM

Functional integration

- Analyses of inter-regional effects
- What are the interactions between the elements of a neuronal system?
- Univariate & Multivariate analysis

Functional connectivity

Effective connectivity

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K. Stephan, FIL

Systems analysis in functional neuroimaging

Functional integration

Functional connectivity

- Temporal correlations between spatially remote areas
- **MODEL-FREE**
- **Exploratory**
- **Data Driven**
- **No Causation**
- **Whole brain connectivity**

PPI

Effective connectivity

- The influence that one neuronal system exerts over another
- **MODEL-DEPENDENT**
- **Confirmatory**
- **Hypothesis driven**
- **Causal (based on a model)**
- **Reduced set of regions**

D. Gitelman
K. Stephan, FIL; S. Whitfield-Gabrieli

Factorial Design: Definition and representations

Task factor

Stimulus factor	Task A	Task B
Stim 1	T_A / S_1	T_B / S_1
Stim 2	T_A / S_2	T_B / S_2

$$y = (T_A - T_B)\beta_1 + (S_1 - S_2)\beta_2 + (T_A - T_B)(S_1 - S_2)\beta_3 + G\beta_4 + \epsilon$$

main effect of task

main effect of stim. type

interaction

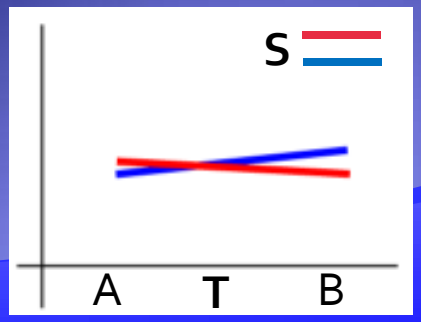
Confounds + error

$$y = T\beta_1 + S\beta_2 + (T \times S)\beta_3 + G\beta_4 + \epsilon$$

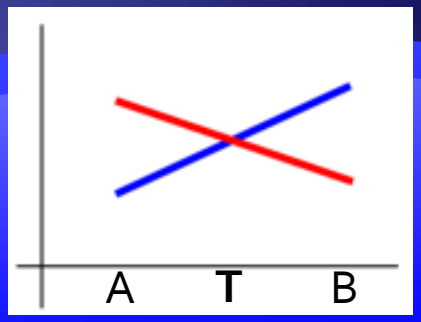
No Interaction

Interaction

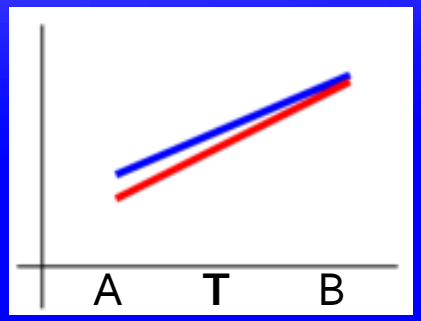
No Main Effect



No main effect
No interaction

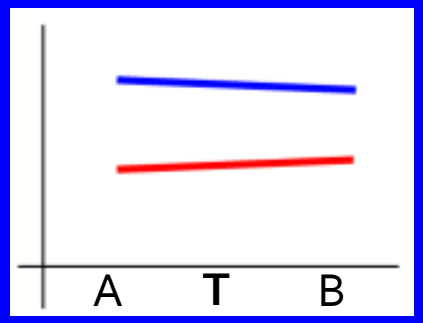


Significant Interaction (T x S)

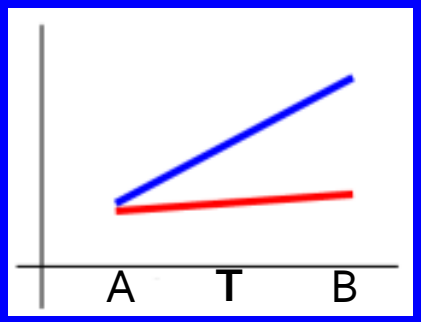


Factor T
is significant

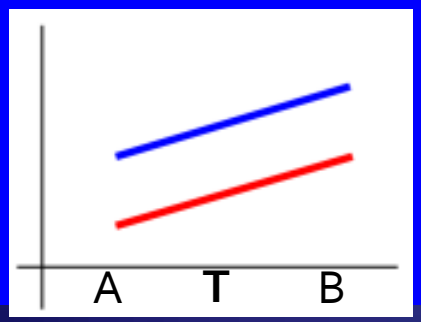
Main Effect



Factor S
is significant



Significant main effects and interaction



Factors T & S
are significant

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Psychological interaction:

- Two (or more) experimental / psychological factors
- Change in regression slope due to the differential response to one experimental condition under the influence of different experimental contexts.

Psychological interactions:

- Task: Letters and tones presented simultaneously. (PET scan).
- Factor 1: Tones presented at different rates.
- Factor 2: Subjects attend and respond to either a target letter (A) or a target tone (low) .

- Is there a differential sensitivity to the presentation rate of tones when paying attention to tones vs. paying attention to letters?

Frith & Friston, Neuroimage, 1996

Psychological interactions:

Presentation rate (R)	Attention (A): Tones	Attention (A): Letters
Stim 1	A_T/R_1	A_L/R_1
Stim 2	A_T/R_2	A_L/R_2
Stim 3	A_T/R_3	A_L/R_3

$$y = \boldsymbol{A\beta_1} + \boldsymbol{R\beta_2} + (\boldsymbol{A} \times \boldsymbol{R})\boldsymbol{\beta_3} + G\beta_4 + \epsilon$$

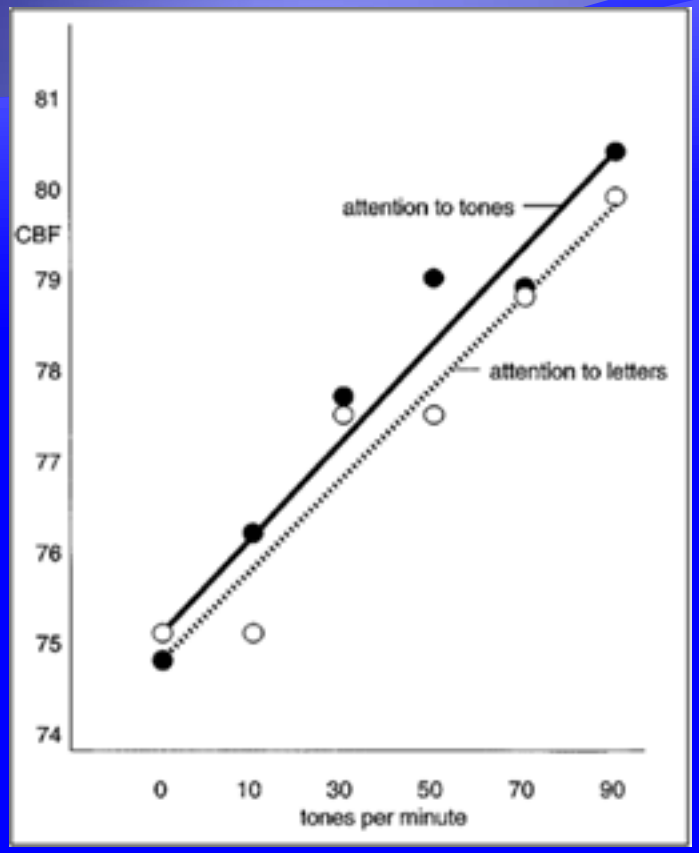
Tones vs. Letters

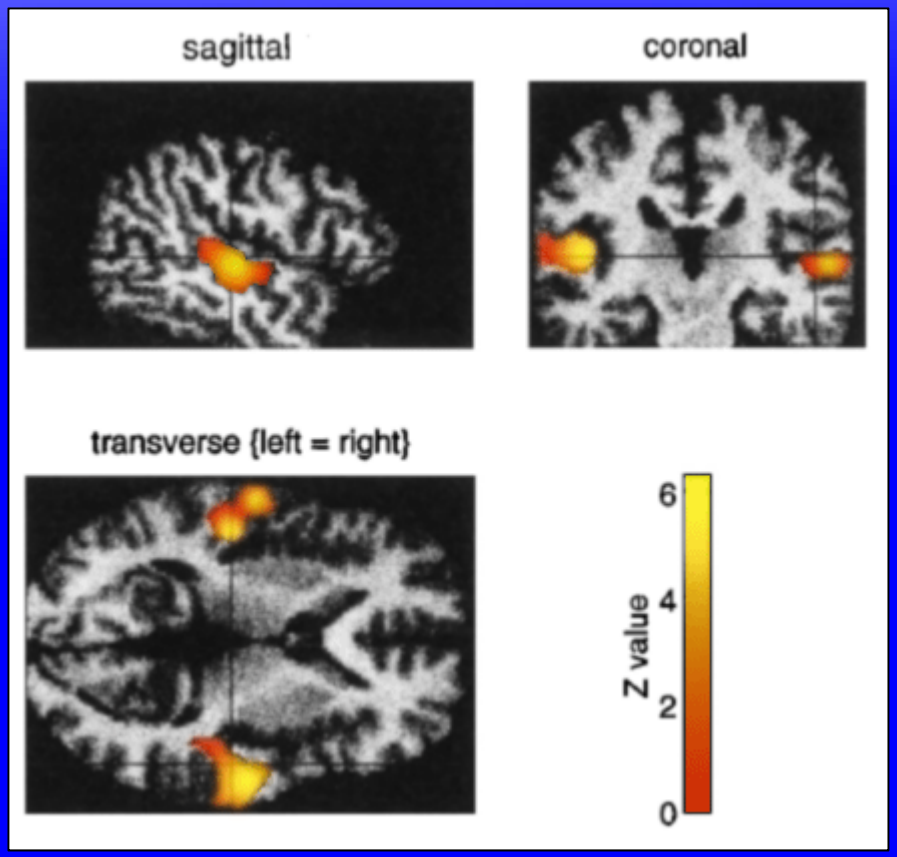
Rate of tones

interaction

Frith & Friston, Neuroimage, 1996

Main effect of tone presentation rate

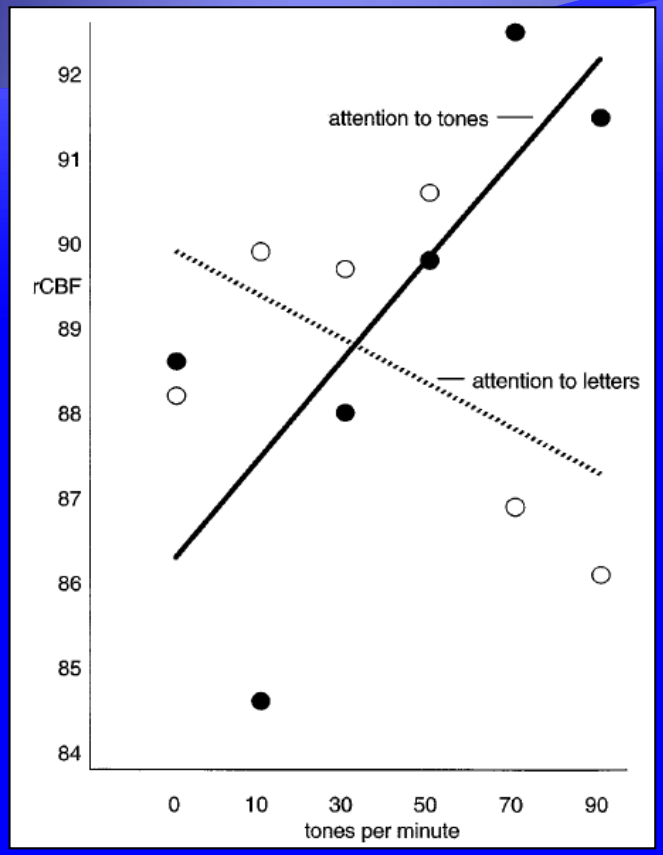


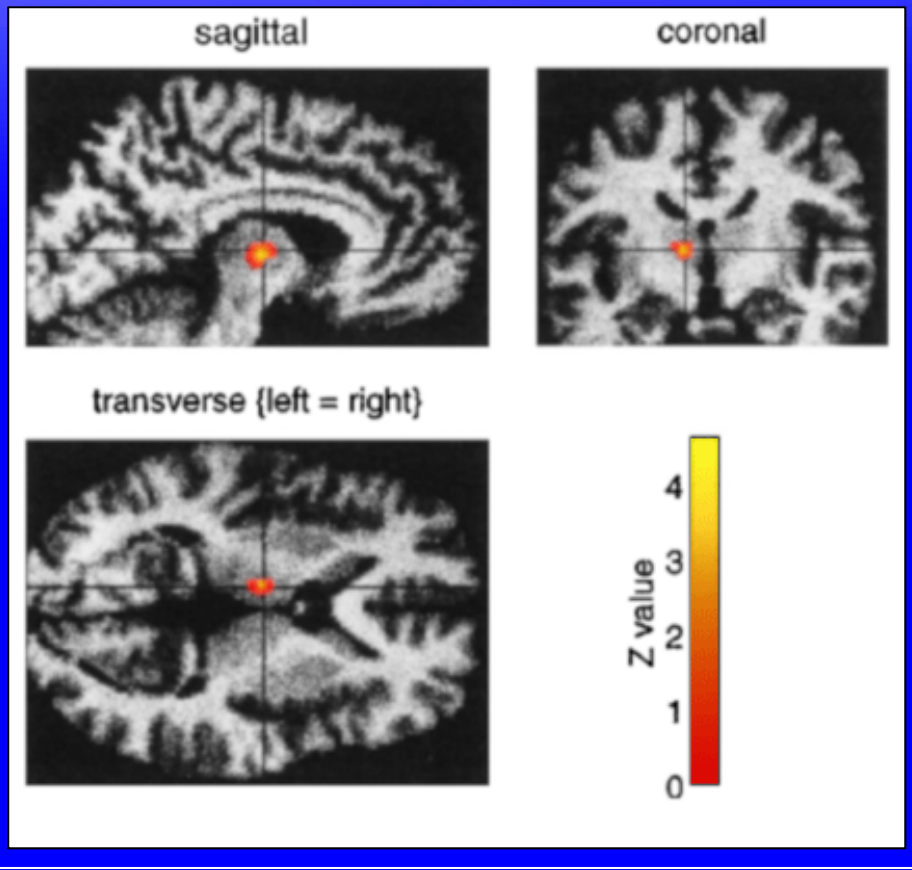


Activity in auditory cortex varies by presentation rate regardless of whether subjects paid attention to tones or letters.

Frith & Friston, Neuroimage, 1996

Interaction between attention and presentation rate.





Activity in the right thalamus is influenced by presentation rate of tones when subjects attended to tones vs. attending to letters.

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Frith & Friston, Neuroimage, 1996

Physiophysiological interaction

- Two (or more) physiological factors (i.e., neural activity signals)
- Change in regression slope due to the differential response of the signal (neural activity) from region 1 due to the signal from region 2.

Attention to visual motion

Key

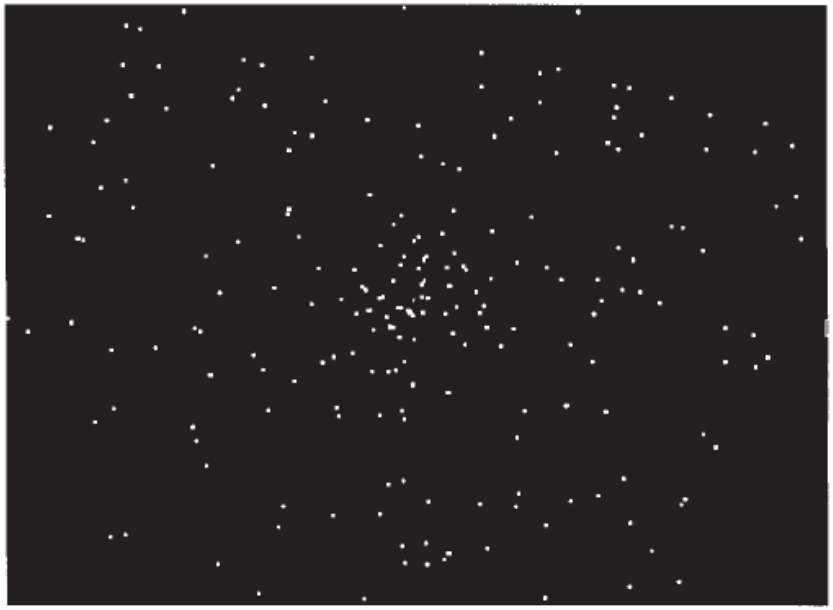
M = Dummy scans (discarded)

F = Fixation (central dot)

A = Attention: radially moving dots. Subjects told to detect changes in speed of dots (no changes actually occurred during scanning).

N = No attention: radially moving dots viewed passively.

S = Stationary: 250 stationary dots



	Run 1											Run 2									
Condition	M	F	A	F	N	F	A	F	N	S	M	F	A	F	N	F	A	F	N	S
Volumes	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time (s)	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32

	Run 3 (counterbalanced)											Run 4 (counterbalanced)									
Condition	M	F	N	F	A	F	N	F	A	S	M	F	N	F	A	F	N	F	A	S
Volumes	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time (s)	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32

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Buchel et al, Cereb Cortex, 1997

Attention to motion: physiophysiological interaction design

Task factor

Stimulus factor	Attention	No attention
Motion	T_A/S_1	T_N/S_1
No motion	T_A/S_2	T_N/S_2

$$(T_A - T_N) \rightarrow \Phi$$

Activity in Region 1

$$(S_M - S_S) \rightarrow \Theta$$

Activity in Region 2

$$y = \Phi_{PP}\beta_1 + \Theta_{V1}\beta_2 + (\Phi_{PP} \times \Theta_{V1})\beta_3 + G\beta_4 + \epsilon$$

Region 1 | Region 2 | interaction

Physiophysiological interactions

- Task: Subjects asked to detect speed changes in radially moving dots (fMRI).

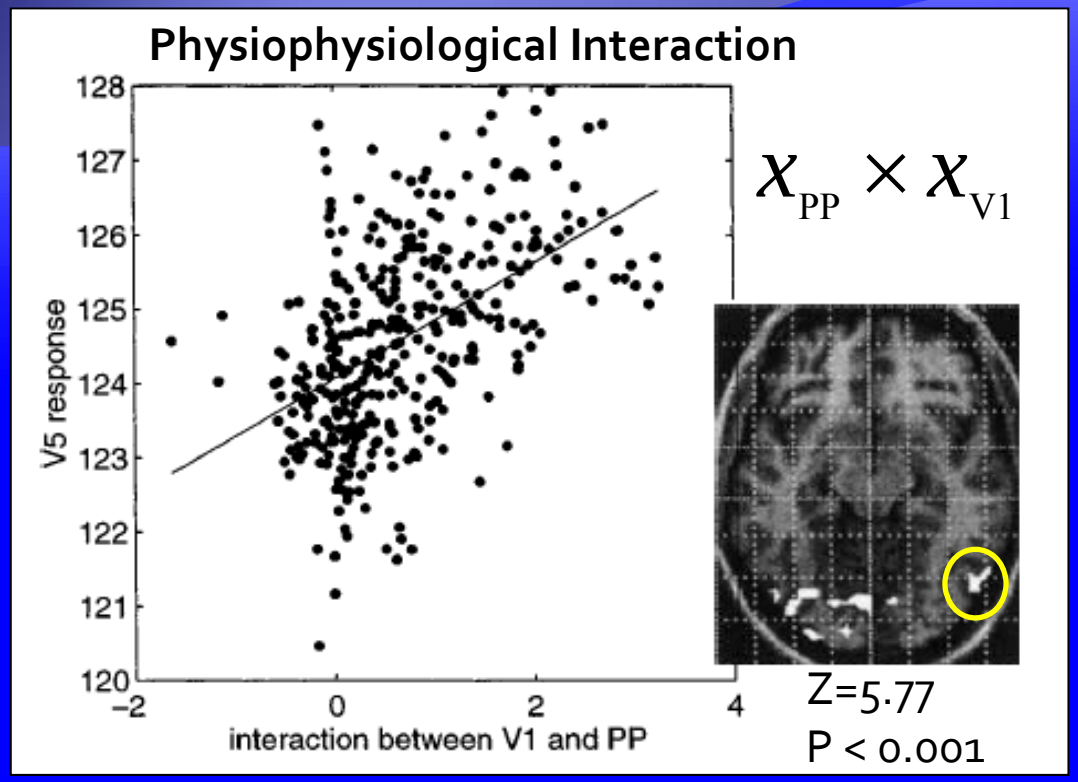
- Does activity in posterior parietal (PP) cortex (attentional area) modulate the response to V1 (motion area) activity (or is there a contribution from PP that depends on V1 activity)?

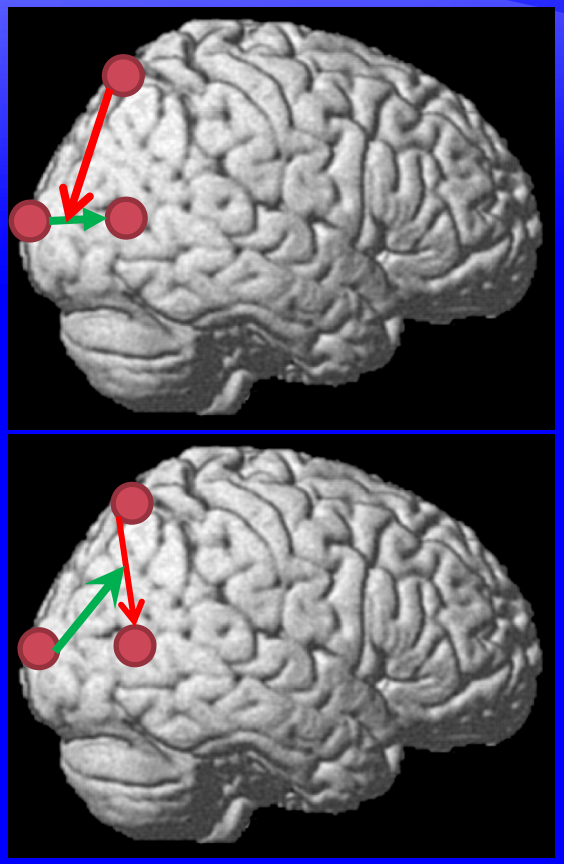
$$y = \Phi_{PP}\beta_1 + \Theta_{V1}\beta_2 + (\Phi_{PP} \times \Theta_{V1})\beta_3 + G\beta_4 + \epsilon$$

Region 1 | Region 2 | interaction

Friston et al, Neuroimage, 1997

Interaction effect in V5





- modulation of the V1 → V5 contribution by PP?
- modulation of the PP → V5 contribution by V1?

Friston et al, Neuroimage, 1997

Psychophysiological interactions

- 1 Physiological factor (neural activity)
- 1 Psychological factor (experimental context)

- Change in regression slope due to the differential response of the signal from one region under the influence of different experimental contexts.
- Bilinear model of how the psychological context changes the influence of one area on another.

Friston et al. NeuroImage, 1997

Attention to motion: psychophysiological interaction design

Stimulus factor	Task factor: Attention	Task factor: No attention
Motion	T_A/S_1	T_N/S_1
No motion	T_A/S_2	T_N/S_2

$$(T_A - T_N) \rightarrow T$$

$$(S_M - S_S) \rightarrow \Theta$$

Psychological factor

Activity in Source region

$$y = \boldsymbol{T\beta_1} + \boldsymbol{\Theta_{V1}\beta_2} + (\boldsymbol{T} \times \boldsymbol{\Theta_{V1}})\boldsymbol{\beta_3} + G\beta_4 + \epsilon$$

Task factor

Source Region

interaction

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Psychophysiological interactions:

- Task: Subjects asked to detect speed changes in radially moving dots (fMRI).

- Does the task (attention) modulate the response, to V1 activity, or does activity in V1 influence the response to attention? [Inference on task and regional effects]

$$y = T\beta_1 + \Theta_{V1}\beta_2 + (T \times \Theta_{V1})\beta_3 + G\beta_4 + \epsilon$$

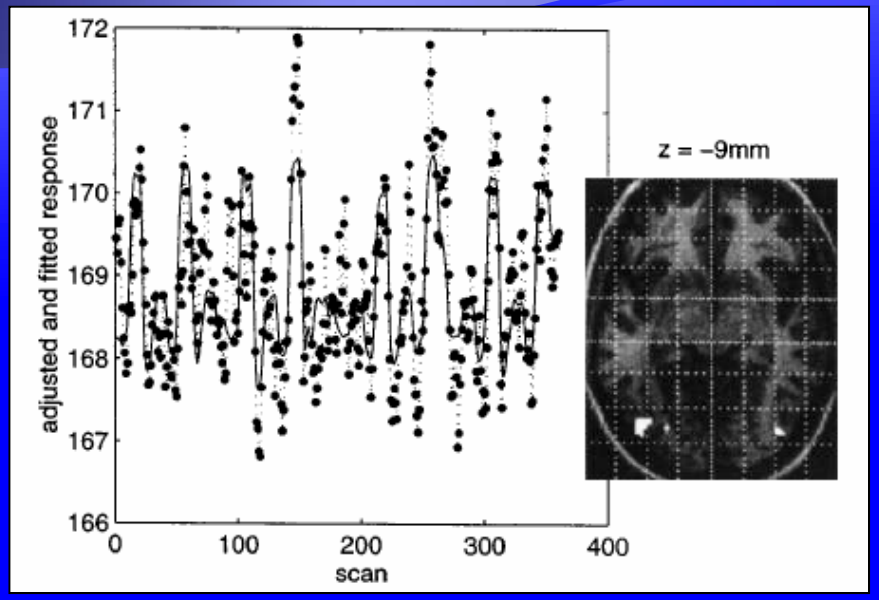
Task factor

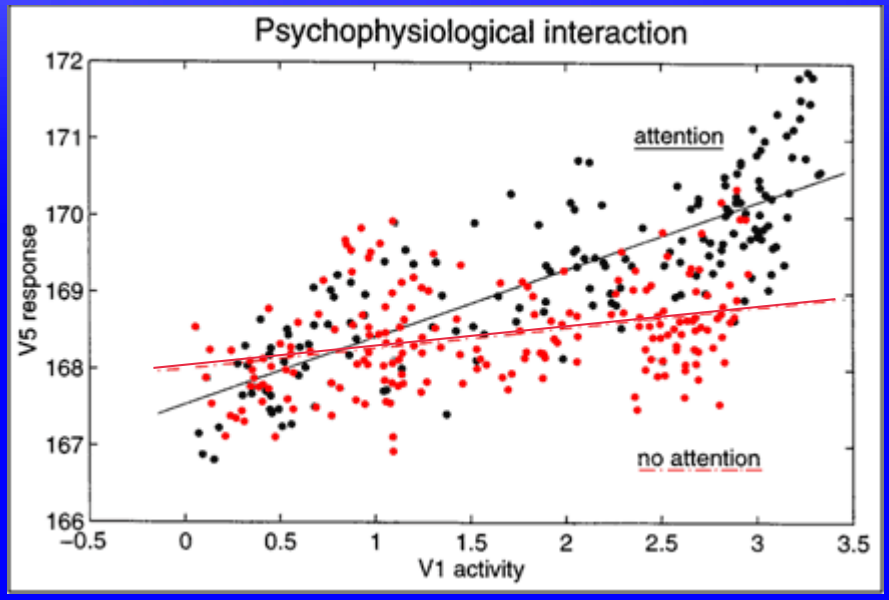
Source Region

interaction

Friston et al, Neuroimage, 1997

Psychophysiologic interaction

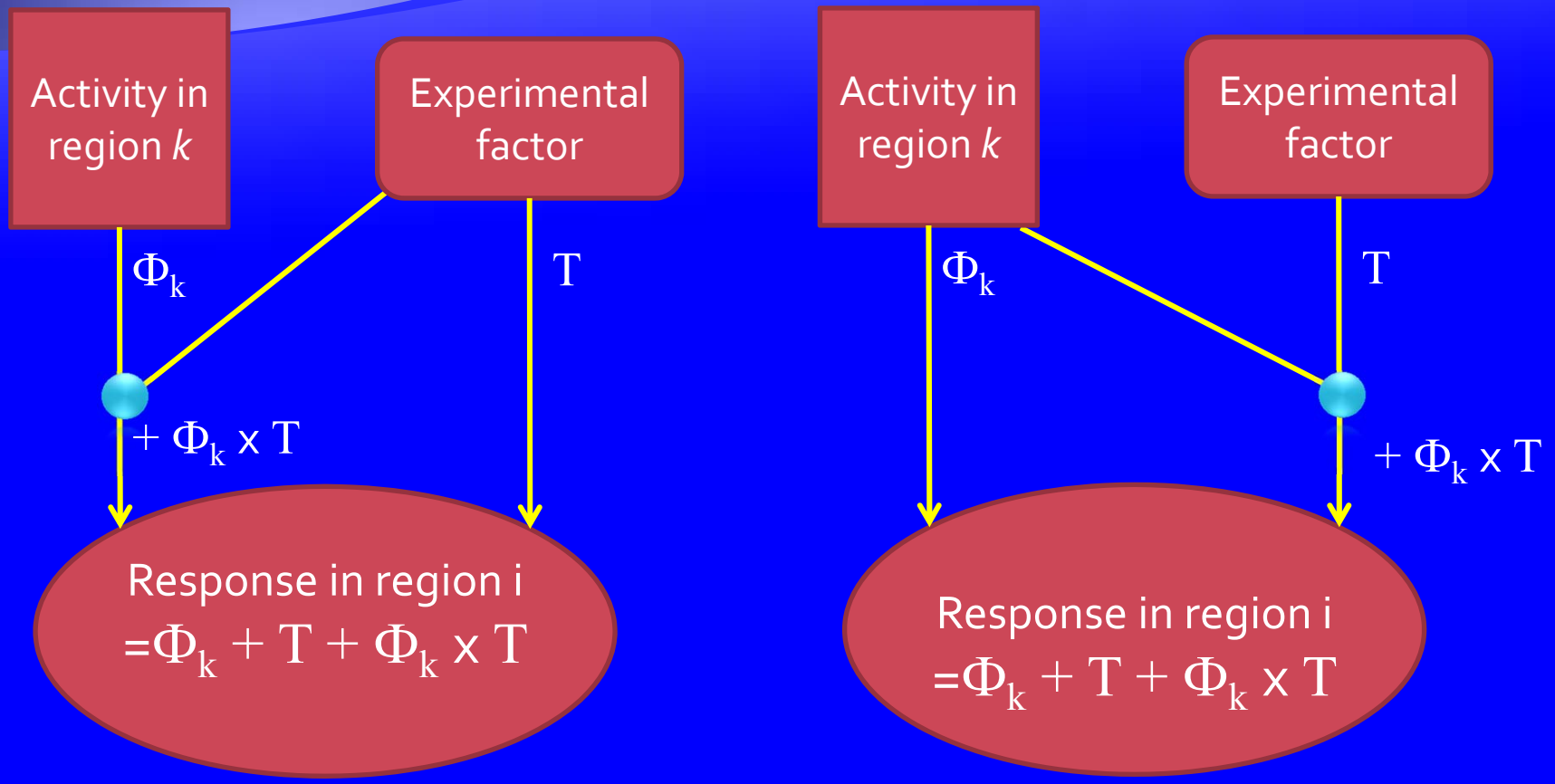




- Two possible interpretations
  - Modulation of the contribution of V1 to V5 by attention (context specific)
  - Modulation of attention specific responses in V5 by V1 inputs (stimulus specific)

Friston et al, Neuroimage, 1997

Two mechanistic interpretations of PPI's.



Context specific modulation of responses to stimulus

Stimulus related modulation of responses to context (attention)

Friston et al, Neuroimage, 1997

PPI vs. correlation

- Are PPI's the same as correlations?
  - No
    - PPI's are based on regressions and **explicitly discount main effects** (discount simple correlations)

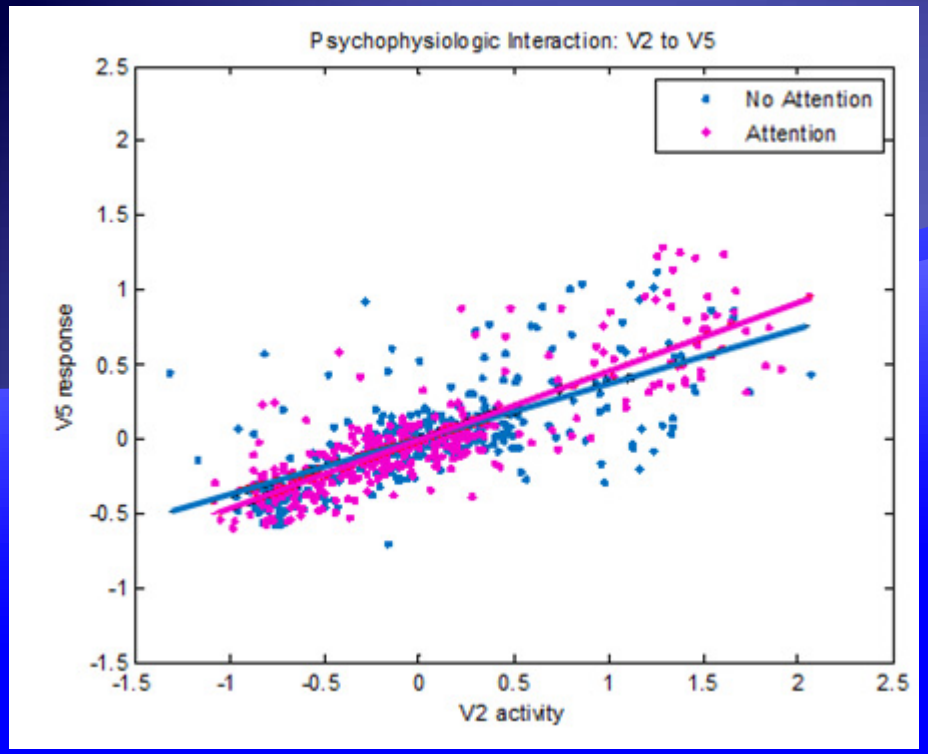
PPI vs. correlations

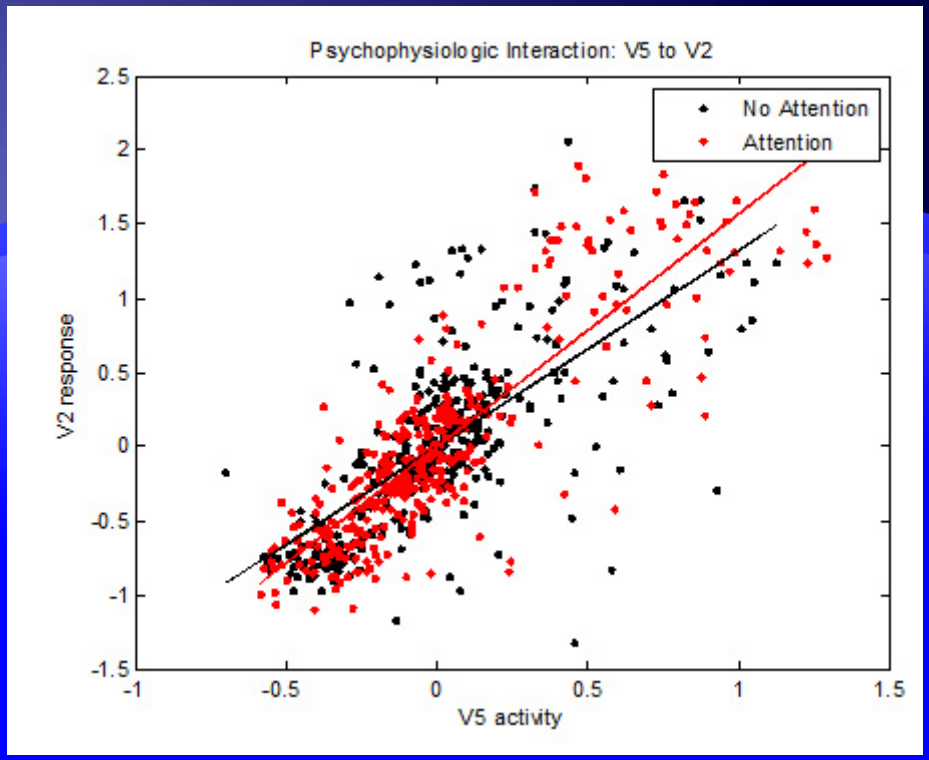
- Kim and Horwitz investigated correlations vs. PPI regression using a biologically plausible neural model.
- PPI results were similar to those based on integrated synaptic activity (gold standard)
- Results from correlations were not significant for many of the functional connections.
- A change in influence between 2 regions may not involve a change in signal correlation

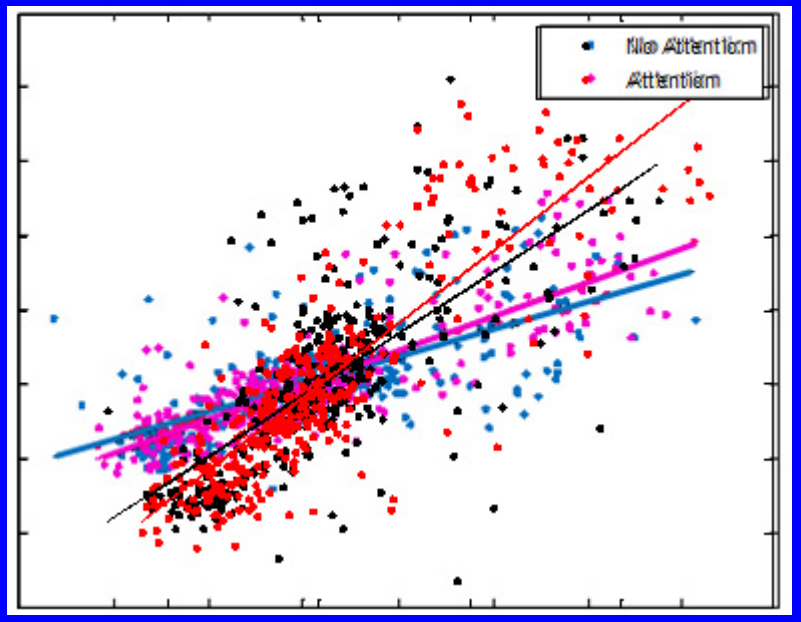
Kim & Horwitz, Mag Res Med, 2008

PPI directionality

- Although PPIs select a source and find target regions, they cannot determine the directionality of connectivity.
- The regression equations are reversible. The slope of A → B is approximately the reciprocal of B → A (not exactly the reciprocal because of measurement error)
- Directionality should be pre-specified and based on knowledge of anatomy or other experimental results.


Psychophysiologic Interaction: V2 to V5
No Attention
Attention
V5 response
V2 activity
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5


Psychophysiologic Interaction: V5 to V2
No Attention
Attention
V2 response
V5 activity
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5


No Attention
Attention

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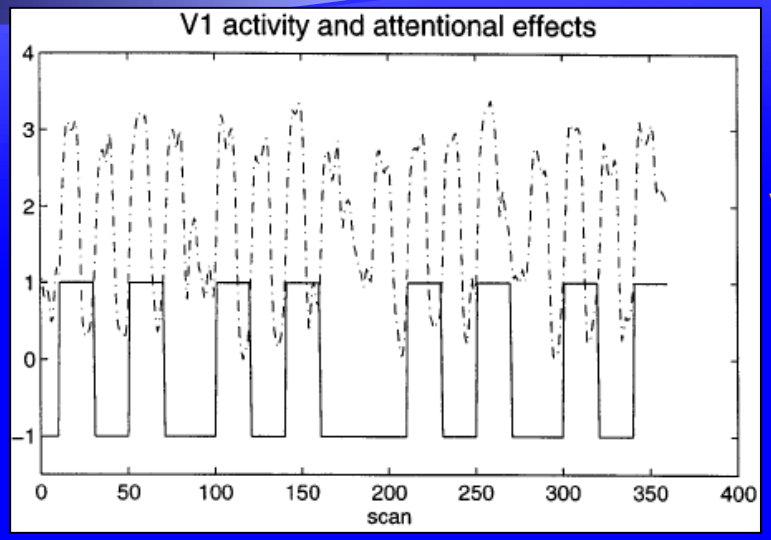
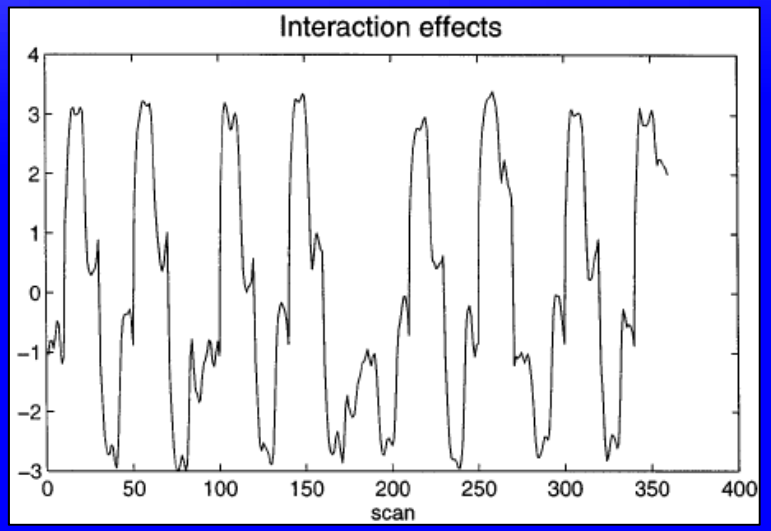
PPI: notes

- Because they consist of only 1 input region, PPI's are models of contributions rather than effective connectivity.
- PPI's depend on factorial designs, otherwise the interaction and main effects may not be orthogonal, and the sensitivity to the interaction effect will be low.
- Problems with PPI's
  - Interaction term not formed correctly (as originally proposed)
  - Analysis can be overly sensitive to the choice of region.

Interaction term: first pass



V1 x Attention



$x_k \times g_p$

- Psychophysiological interaction term originally formed by multiplying measure BOLD signal by context vector (or by another BOLD signal in the case of physiophysiological interactions)

Friston, et al. Neuroimage, 1997

Interaction term (revisited)

- Regional activity measured as a BOLD time series = hemodynamic response ⊗ neural activity
  - ⊗ = convolution
- Initial formulation of PPI estimated the interaction term as BOLD x context vector.
- BUT: Interactions actually occur at a neuronal level!
- Therefore neuronal activity must be estimated from hemodynamic activity
  - But, this is difficult because mapping from BOLD signal to neural signal is non-unique (due to loss of high frequency information) (Zarahn, Neuroimage, 2000)

BOLD vs. neural interactions

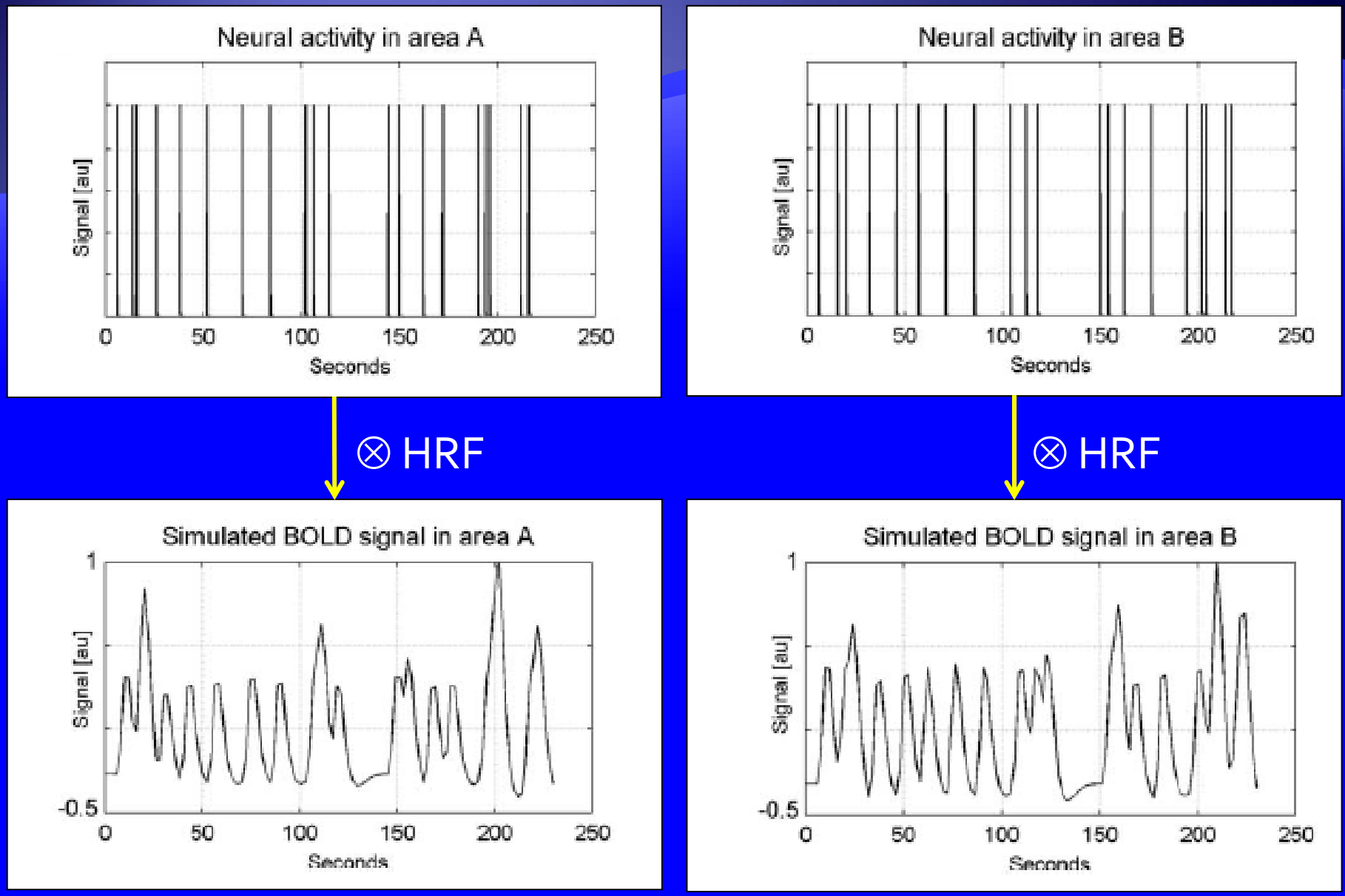
$$y_t = \sum_{\tau} h_\tau x_{t-\tau} \Rightarrow y = Hx$$

y_t = Measured BOLD signal
h_τ = hemodynamic (impulse) response function
$x_{t-\tau}$ = neuronal signal
H = HRF in Toeplitz matrix form

$$y_A y_B = (Hx_A)(Hx_B)$$

$$HPy_A = (HP)(Hx_A)$$

Gitelman et al., Neuroimage, 2003



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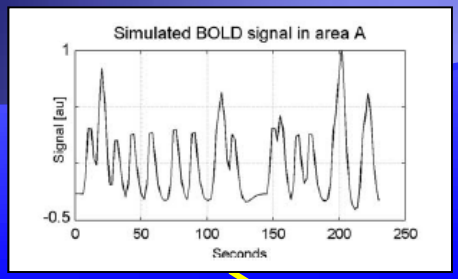
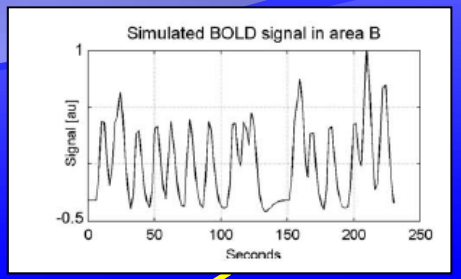
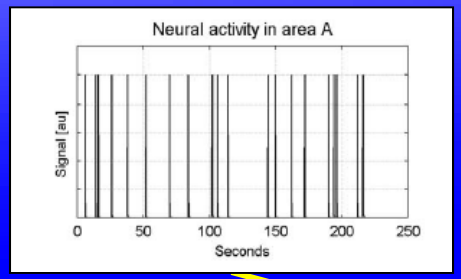
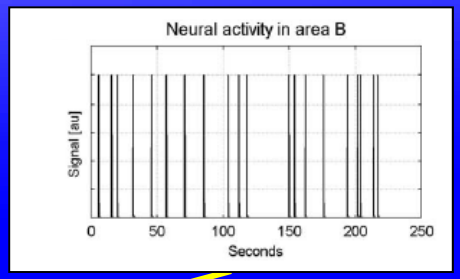
Gitelman et al., Neuroimage, 2003

BOLD vs. neural interactions (example)

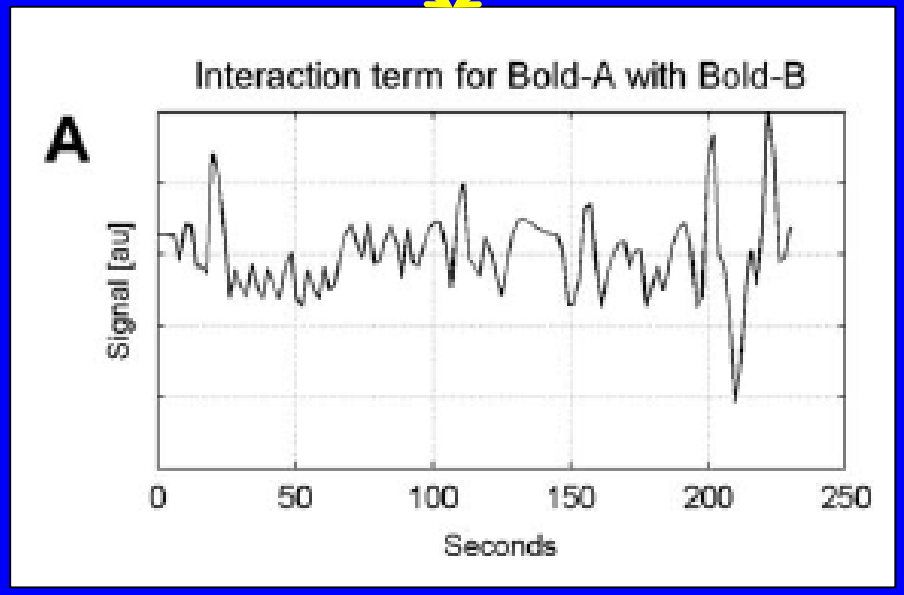


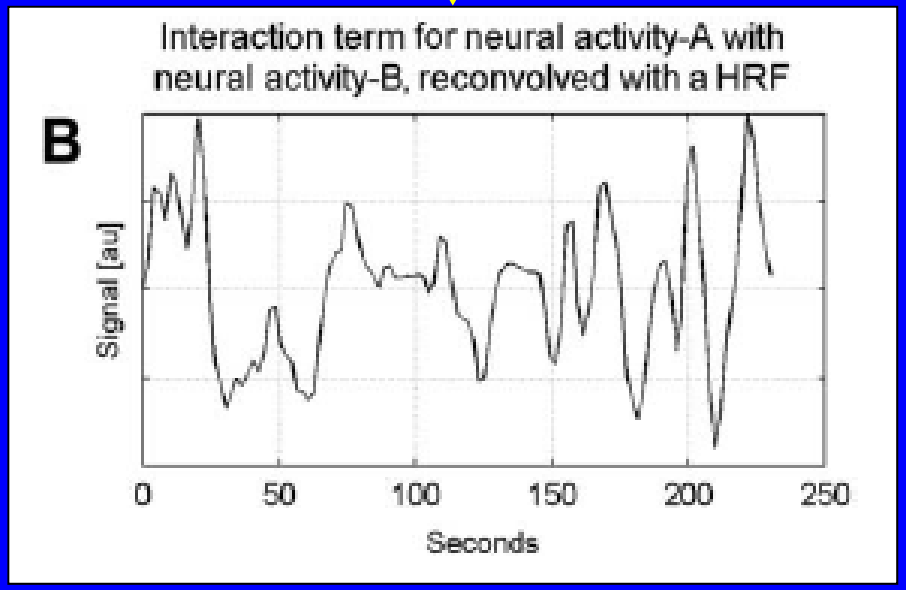






⊗ HRF



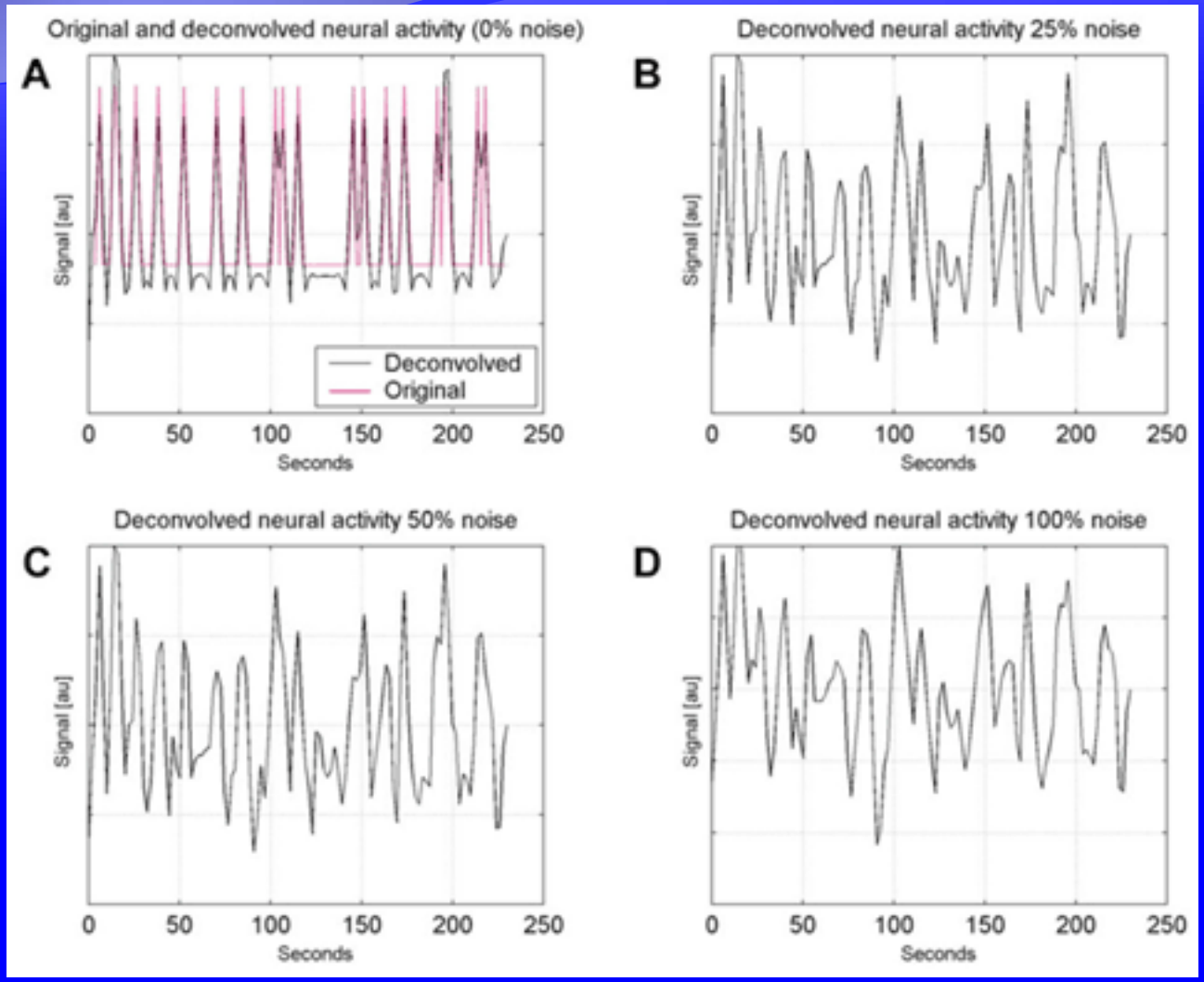


Gitelman et al., Neuroimage, 2003

Deconvolution of BOLD signal

- Can try using a maximum likelihood estimator (i.e., least squares) but this runs into trouble with high-frequency components.
  - Zarahn constrained the estimates to particular temporal intervals. (Zarahn, Neuroimage, 2000)
- Can try using a Weiner filter, but this requires high SNR and an estimate of the noise spectral density. (Glover, Neuroimage, 1999)
- Use empirical Bayes deconvolution to finesse the noise estimates by setting the prior precisions on the high frequencies to 0. (Gitelman, Neuroimage, 2003)

Deconvolution (effect of noise)



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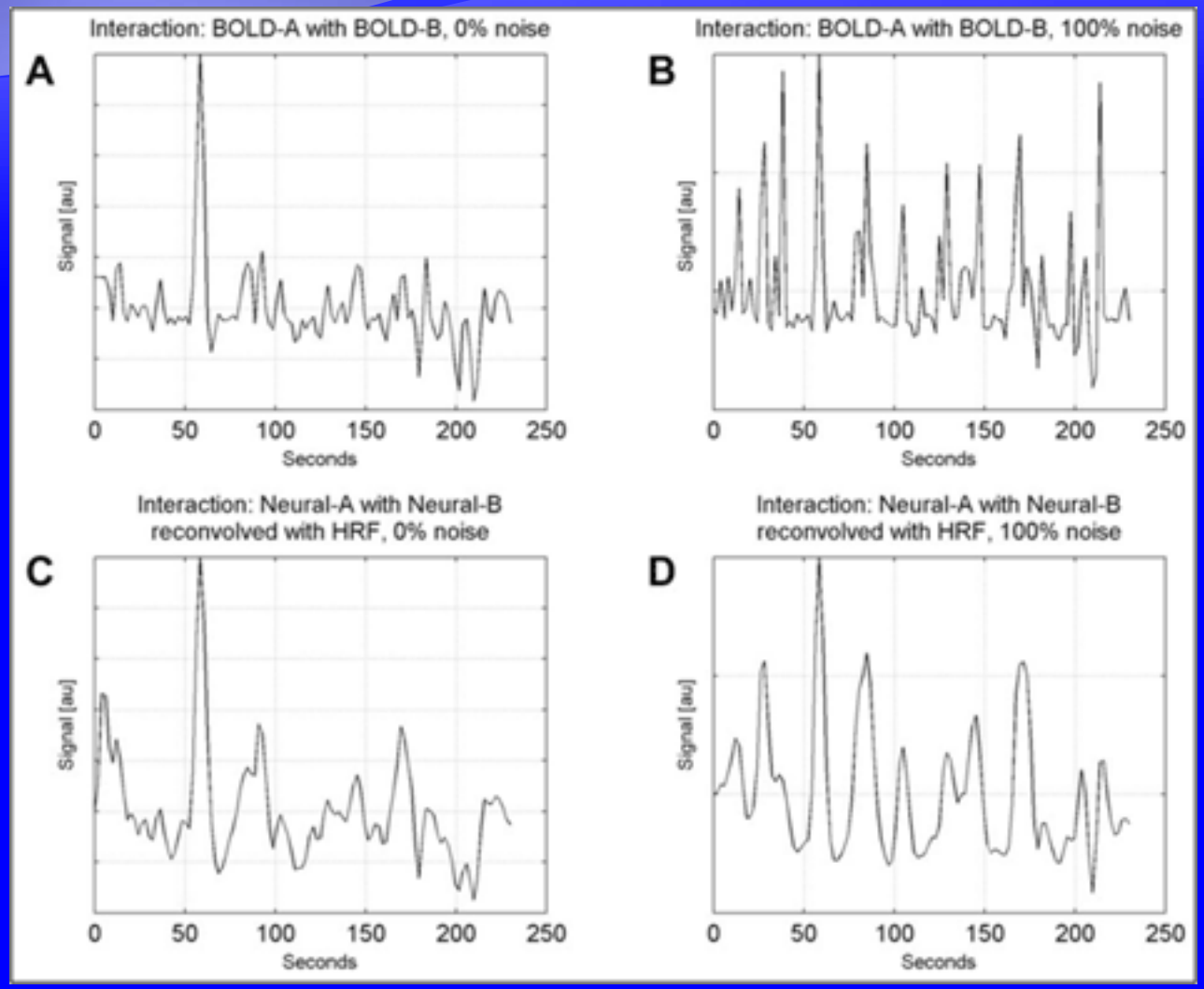
Gitelman et al., Neuroimage, 2003

BOLD vs. neural interactions (effect of noise)

BOLD

Neural



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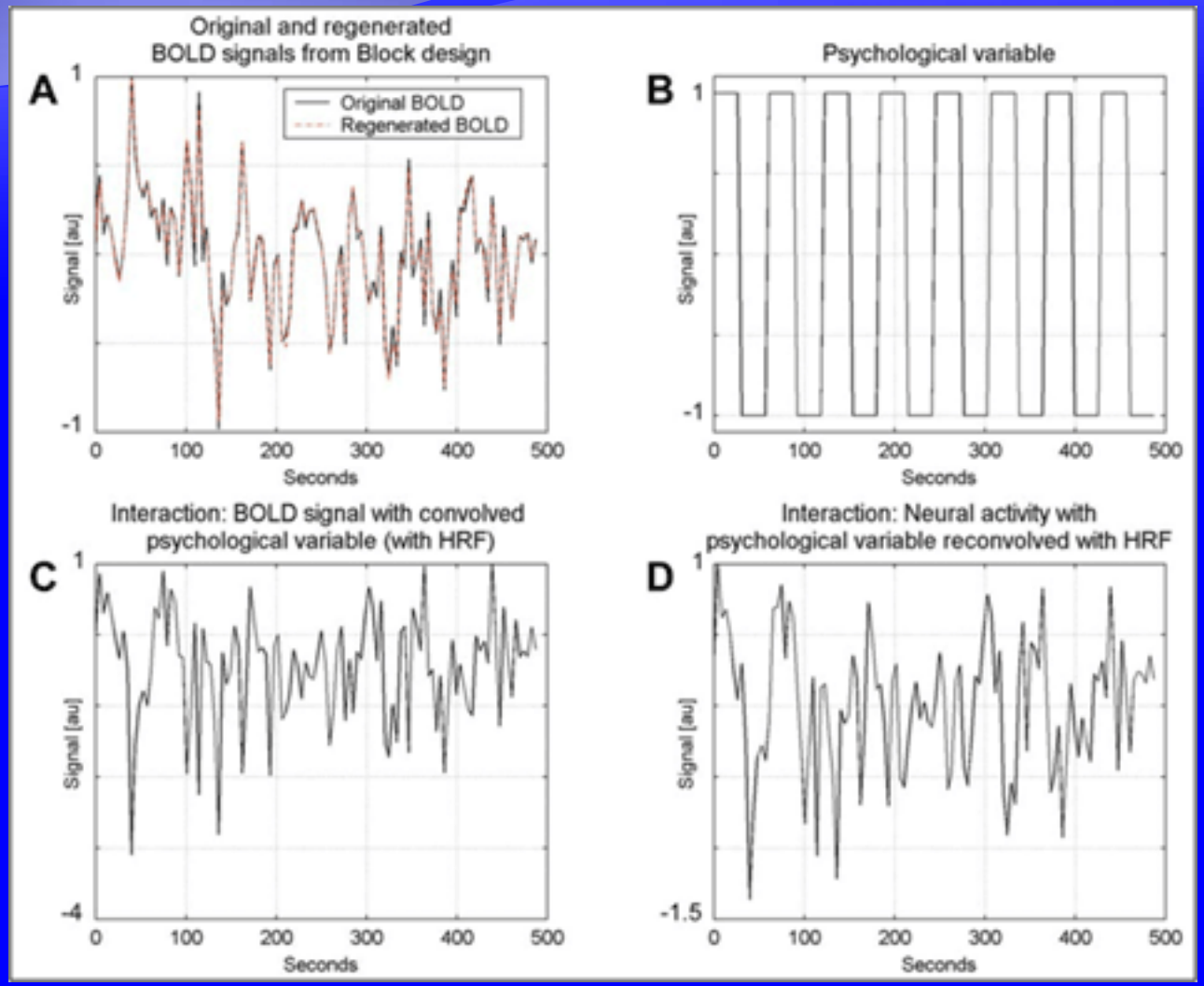
Gitelman et al., Neuroimage, 2003

BOLD vs. neural interactions (block design)



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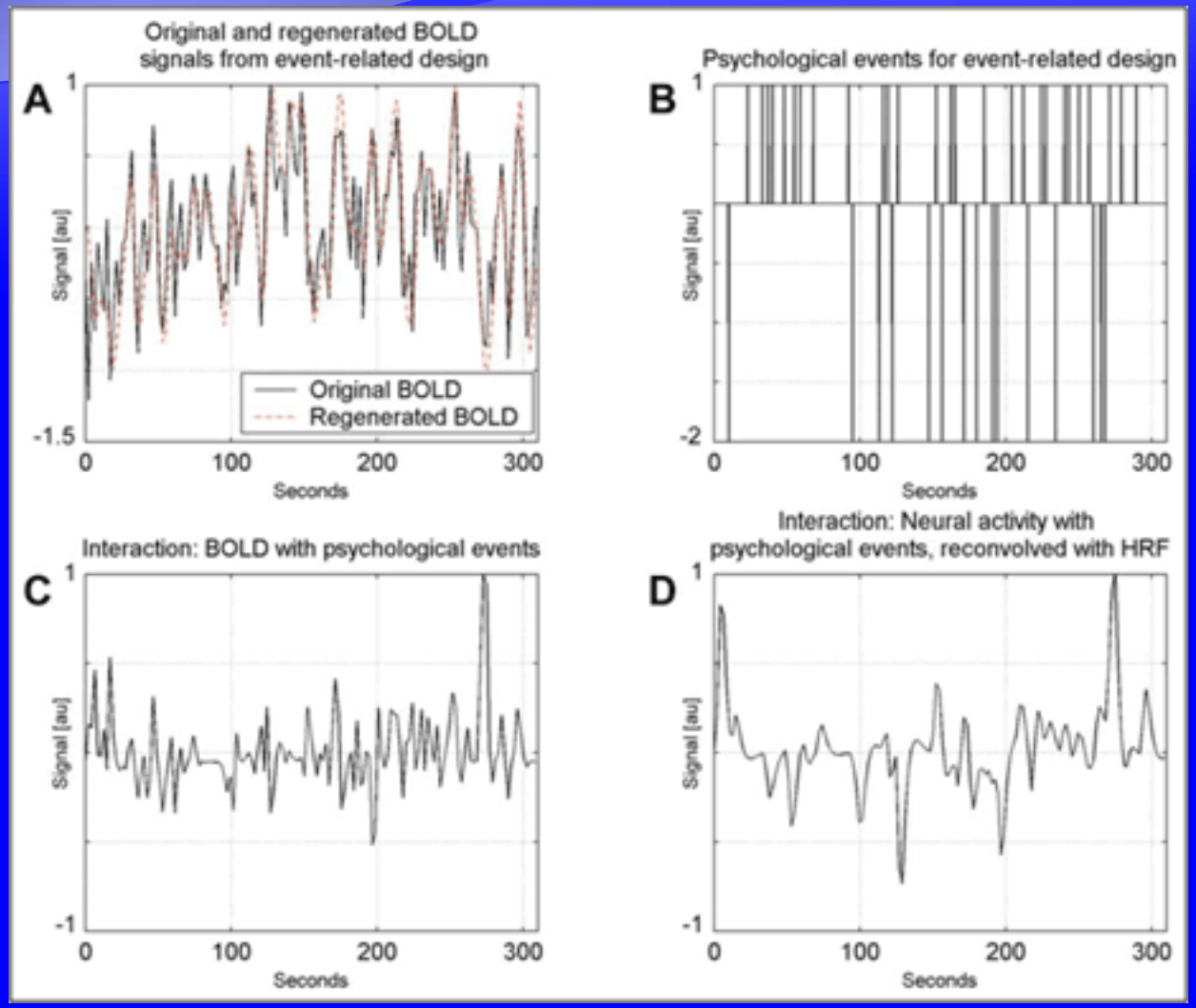
Gitelman et al., Neuroimage, 2003

BOLD vs. neural interactions (event-related design)



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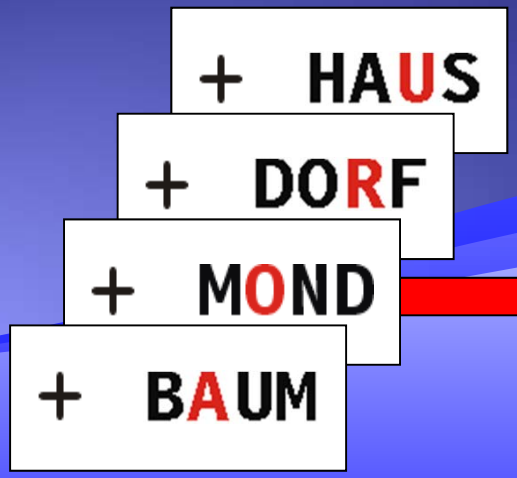
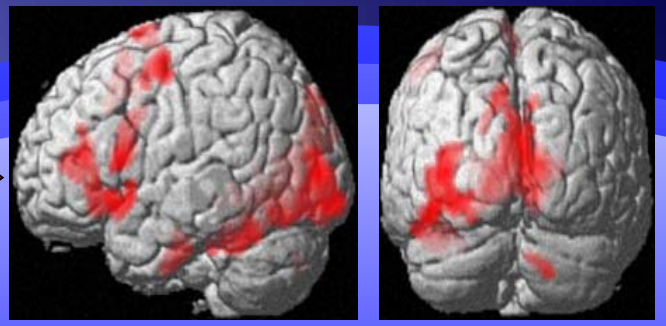
Gitelman et al., Neuroimage, 2003

PPI EXAMPLES

Task-driven lateralisation



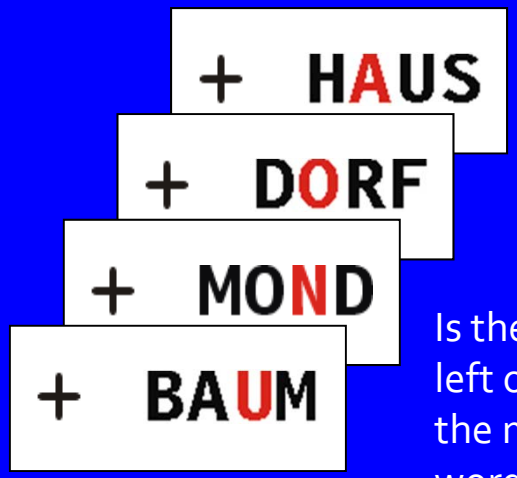
Does the word contain the letter A or not?



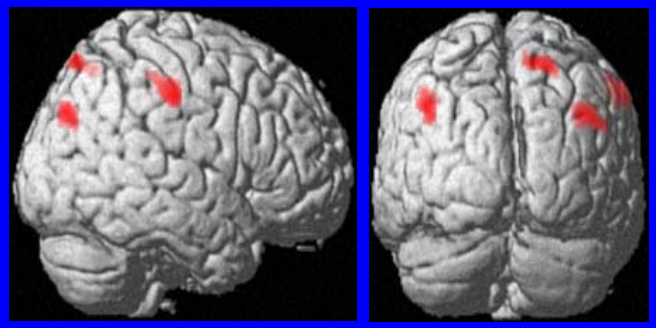
letter decisions > spatial decisions

time

group analysis (random effects), n=16, p<0.05 corrected analysis with SPM2



Is the red letter left or right from the midline of the word?

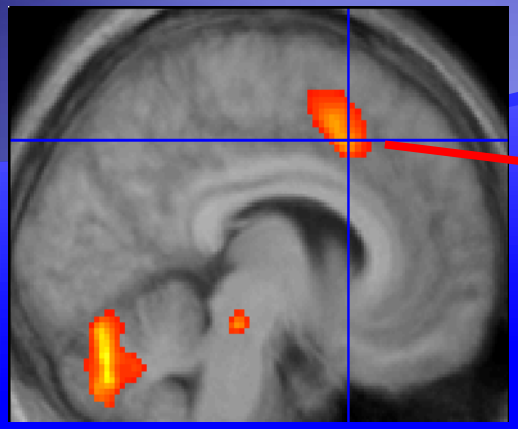


spatial decisions > letter decisions

D. Gitelman

Stephan et al, Science, 2003

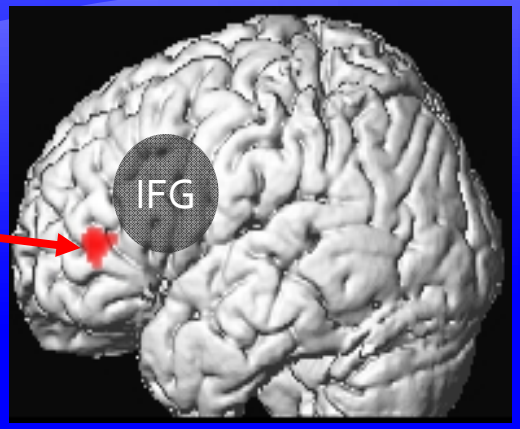
Bilateral ACC activation in both tasks – but asymmetric connectivity !



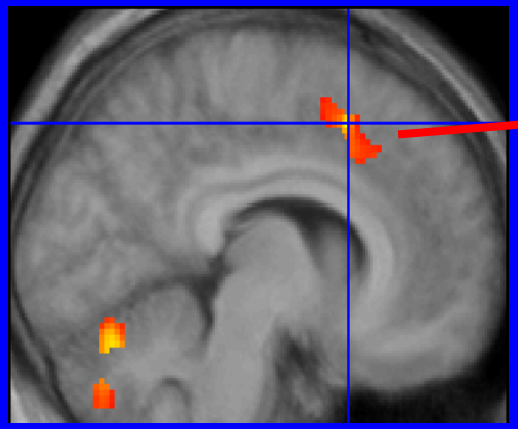
left ACC (-6, 16, 42)

group analysis
random effects (n=15)
p<0.05, corrected (SVC)

letter vs. spatial decisions

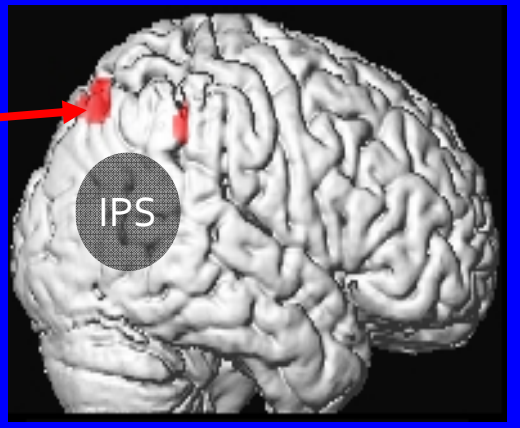


Left ACC → left inf. frontal gyrus (IFG): increase during letter decisions.



right ACC (8, 16, 48)

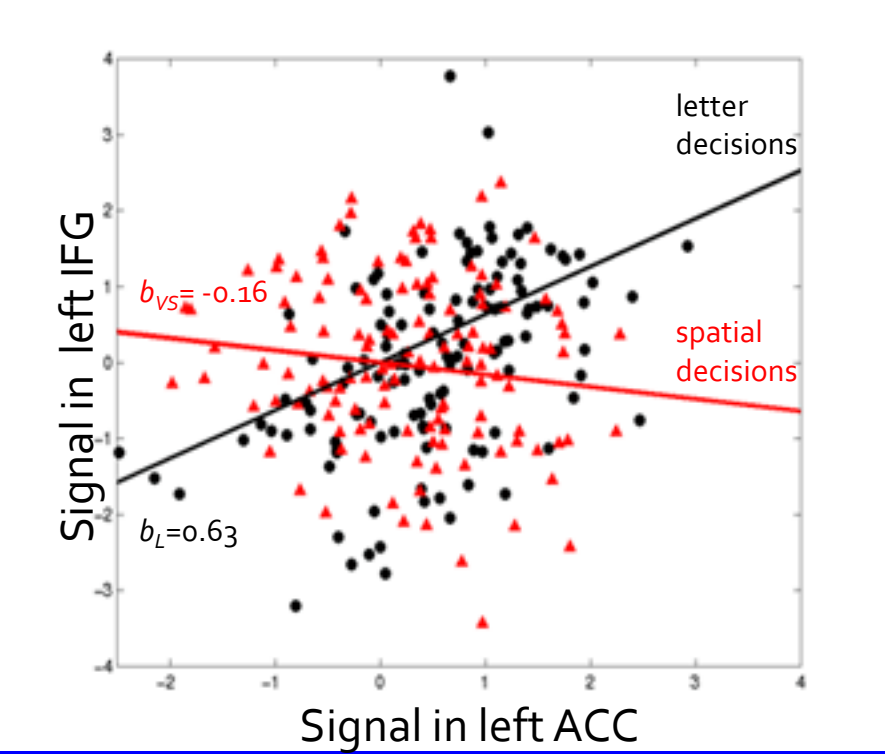
spatial vs. letter decisions



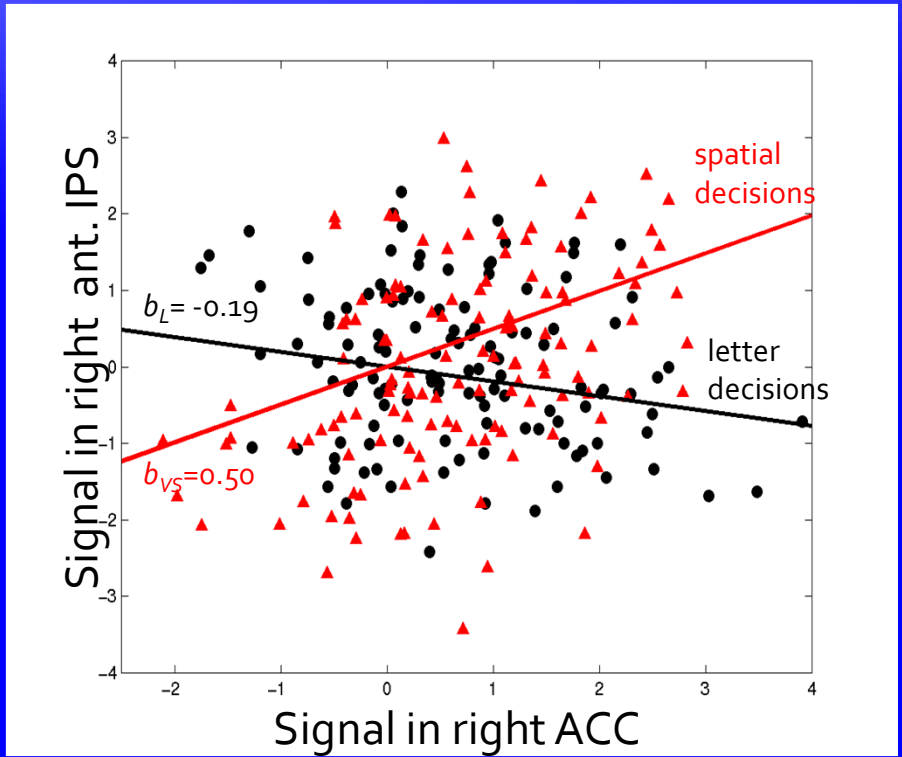
Right ACC → right IPS: increase during spatial decisions.

Stephan et al, Science, 2003

PPI single-subject example



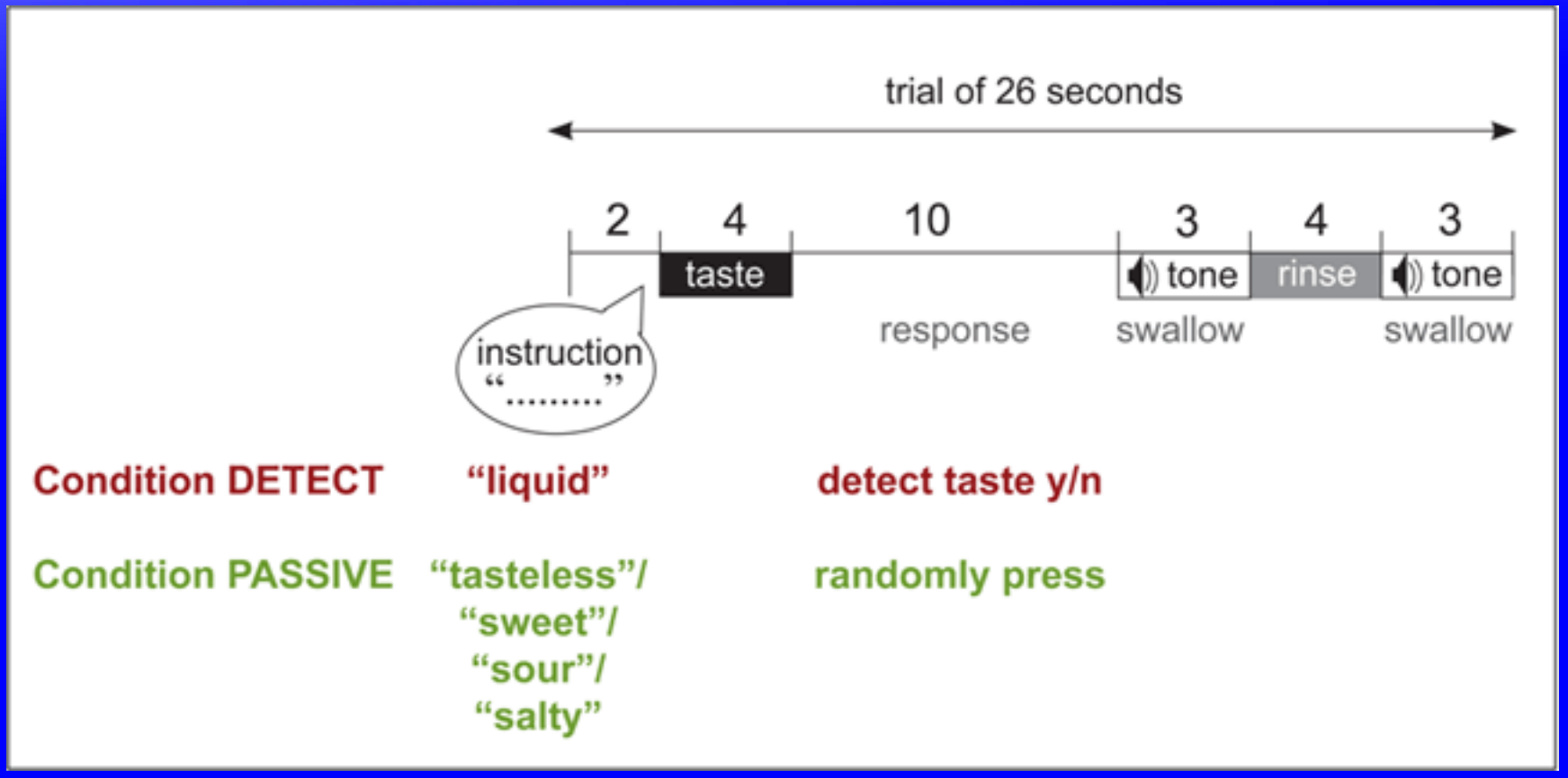
Left ACC signal plotted against left IFG



Right ACC signal plotted against right IPS

Stephan et al, Science, 2003

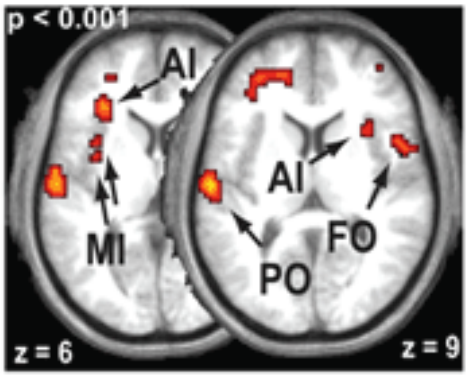
Interactions between the attentional and gustatory networks

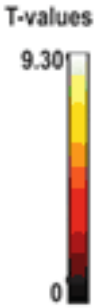


Veldhuizen et al., Chem Senses, 2007

Main effects:
Detect tasteless – Passive tasteless

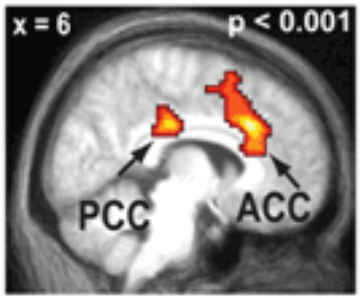
Activation of multiple areas within insula and operculum

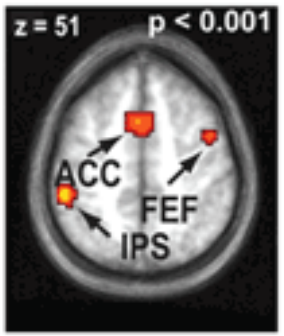




AI = anterior insula
FO = frontal operculum
MI = mid insula
PO = parietal operculum

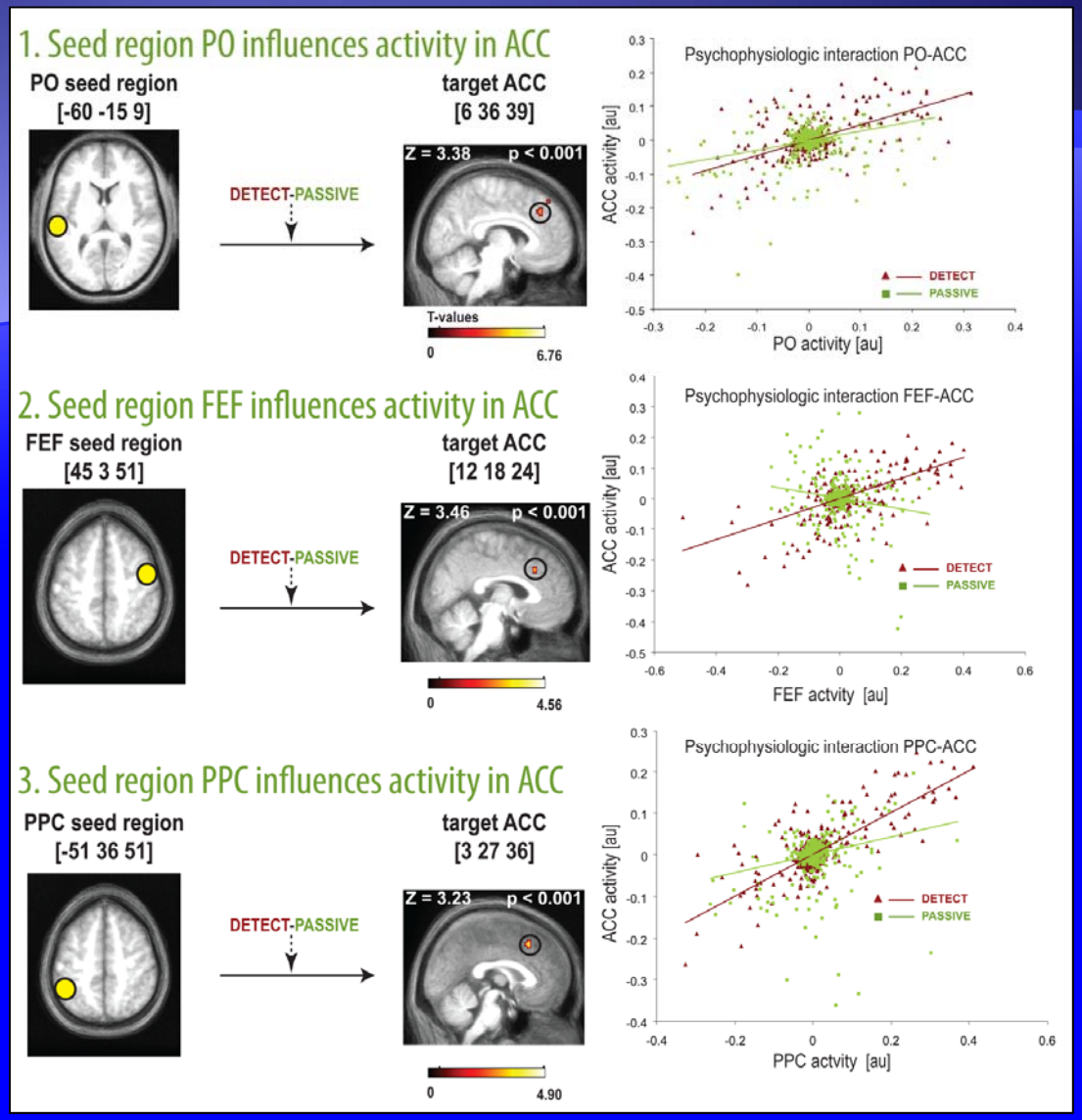
Activation of canonical attention network





PCC = posterior cingulate cortex
ACC = anterior cingulate cortex
IPS = intraparietal sulcus
FEF = frontal eye fields

Veldhuizen et al., Chem Senses, 2007



At a lower threshold (P_{unc} = 0.005, influences were seen from FEF, PO and PPC on AI /FO.

D. Gitelman

Veldhuizen et al., OHBM 2009

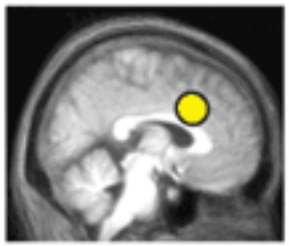
4. Seed region ACC influences activity in AI and FO

target: anterior insula and frontal operculum

[39 12 -3]

Z = 3.77 p < 0.001

ACC seed region
[6 24 33]

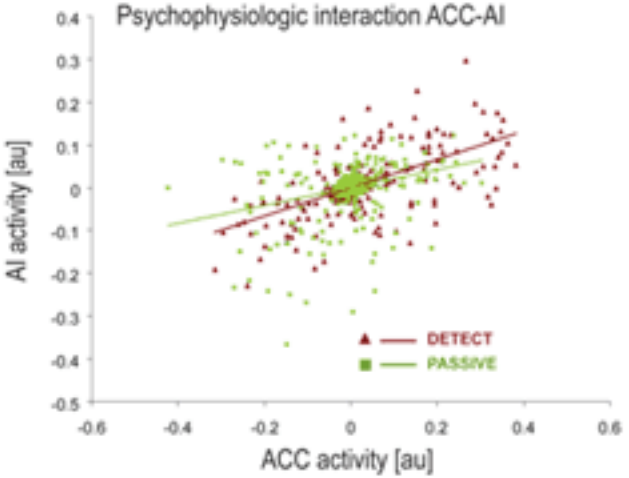


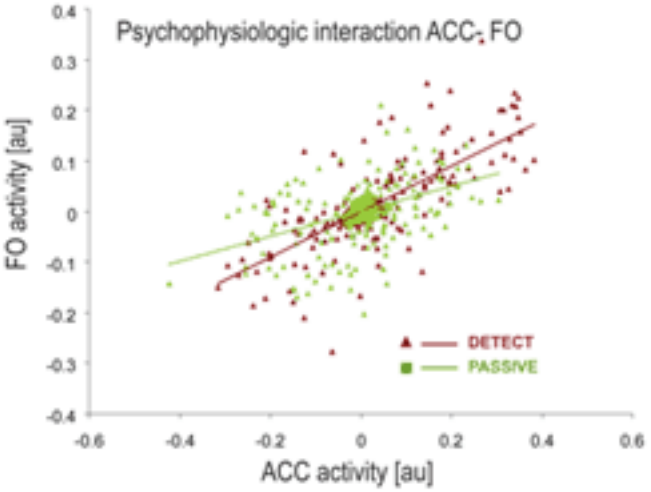
DETECT-PASSIVE

[48 0 6]

Z = 3.38 p < 0.001

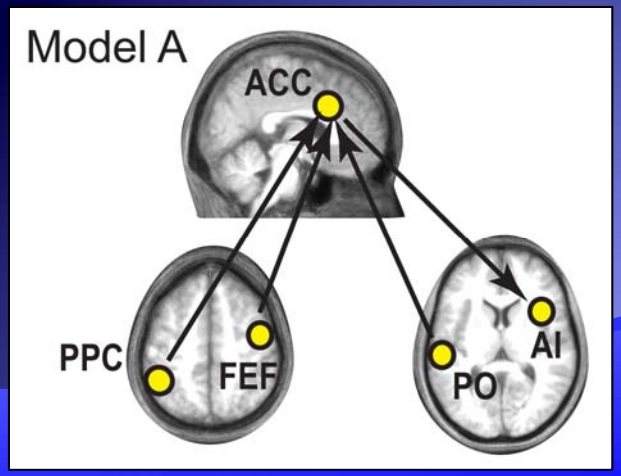
0 6.50

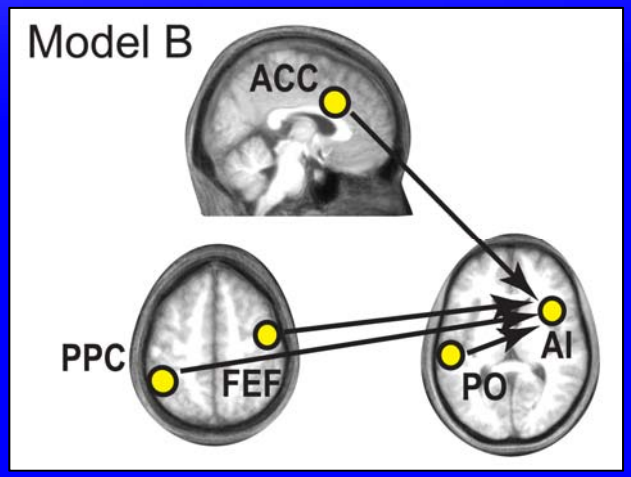


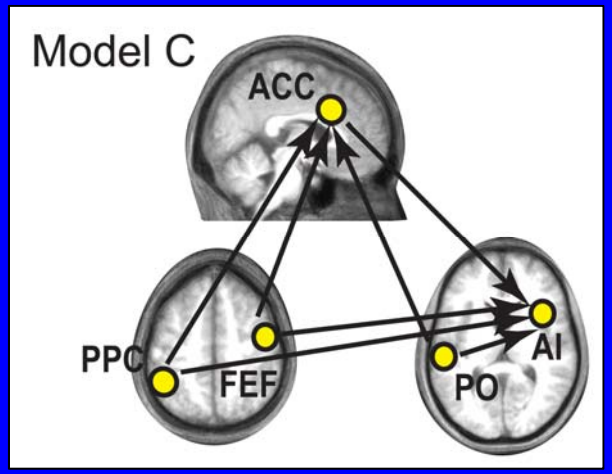


D. Gitelman

Veldhuizen et al., OHBM 2009







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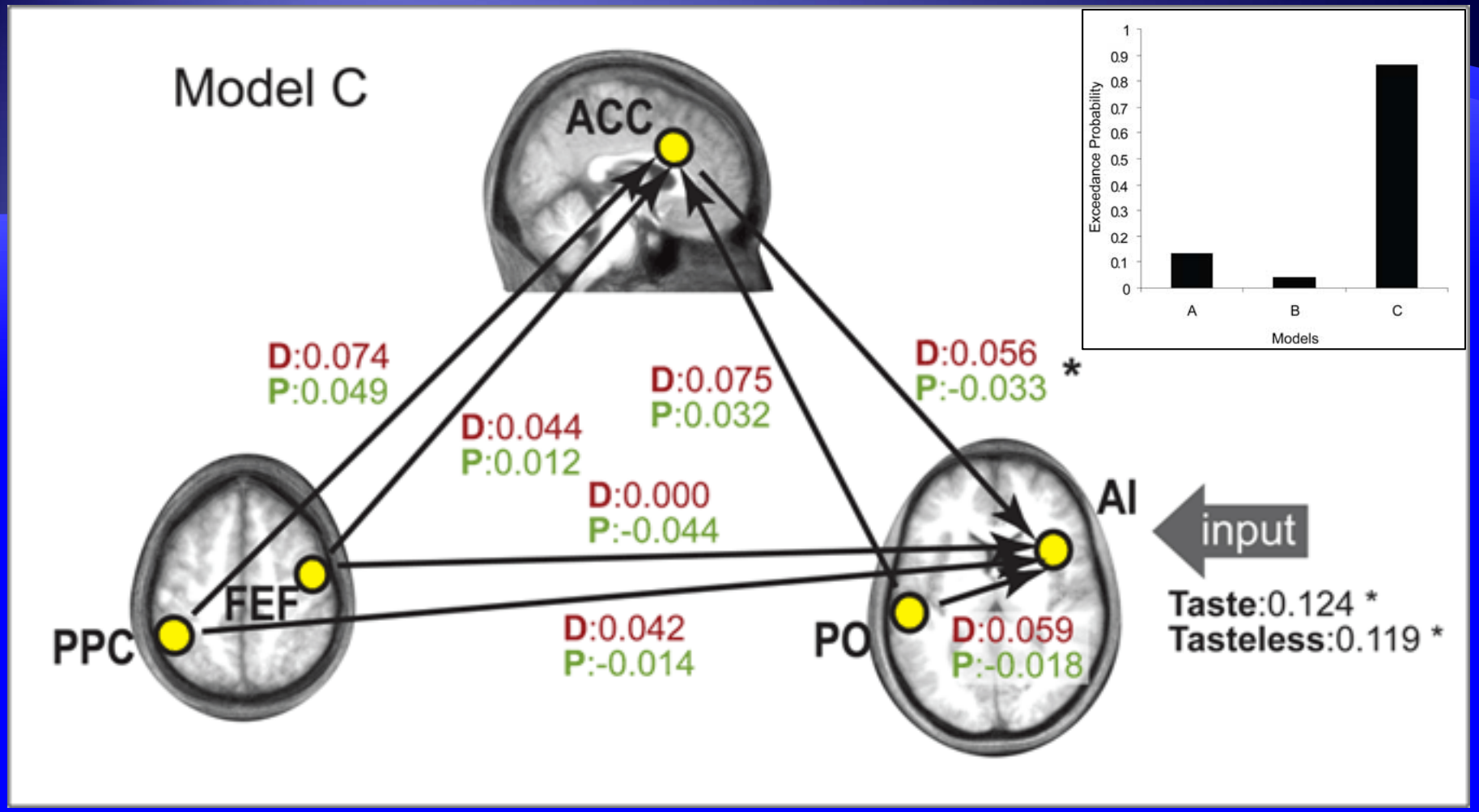
Veldhuizen et al., OHBM 2009


Model C
ACC
D:0.074
P:0.049
D:0.044
P:0.012
D:0.075
P:0.032
D:0.056
P:-0.033
*
D:0.000
P:-0.044
AI
input
FEF
PPC
D:0.042
P:-0.014
PO
D:0.059
P:-0.018
Taste:0.124 *
Tasteless:0.119 *
Exceedance Probability
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
A
B
C
Models

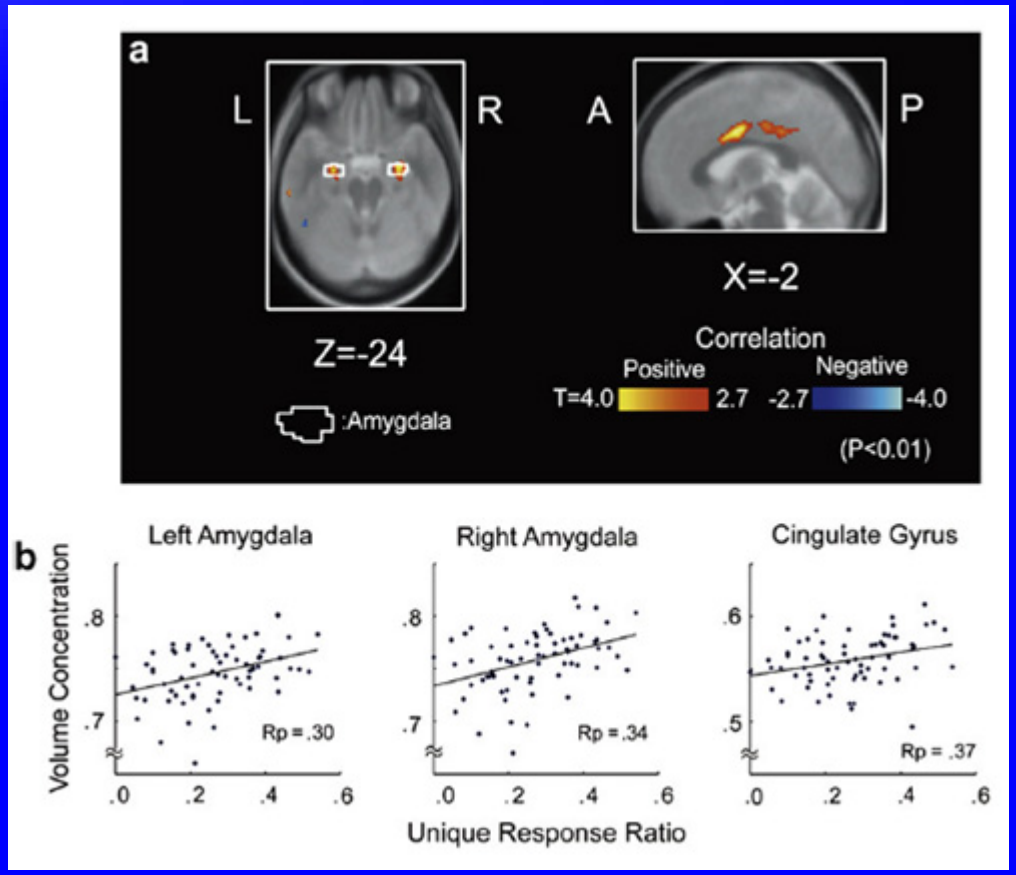
Physiophysiological interaction

- Inkblot test
  - Common/frequent
  - Infrequent
  - Rare/unusual
    - Increased in schizophrenia and certain personality disorders
    - Associated with unusual perception and higher percentage of unusual responses in artistic populations.
  - Since amygdala activity can affect perceptual processing hypothesis is that amygdala is active during inkblot test.

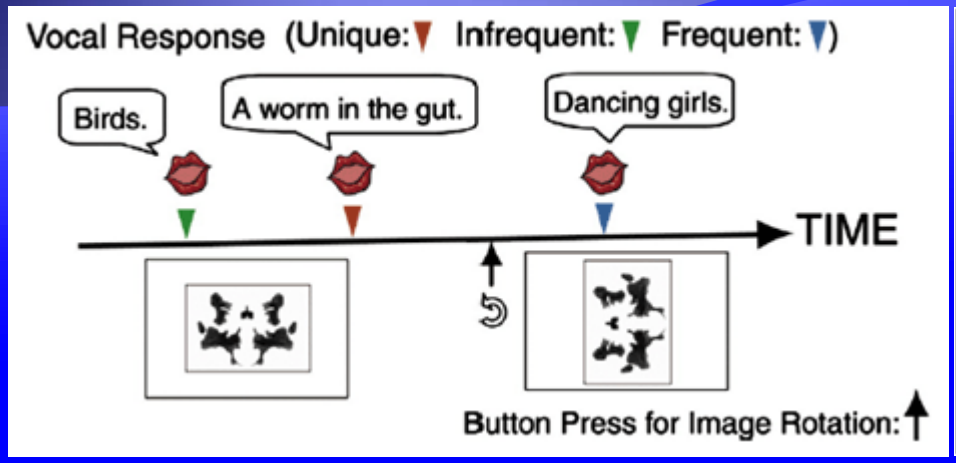
Asari et al., Psych Res, 2010

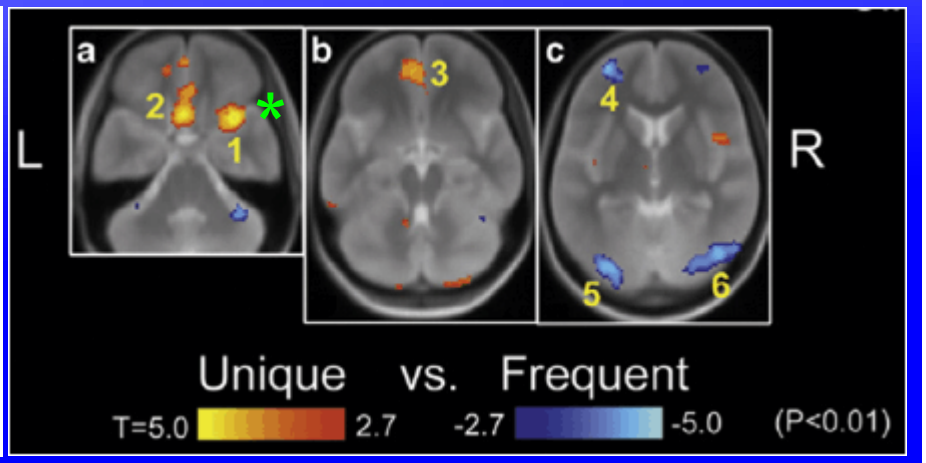
http://www.test-de-rorschach.com.ar/en/inkblots.htm

- VBM demonstrated increased amygdala & cingulate volume in subjects with more unusual responses.



Asari et al., Cortex, 2010

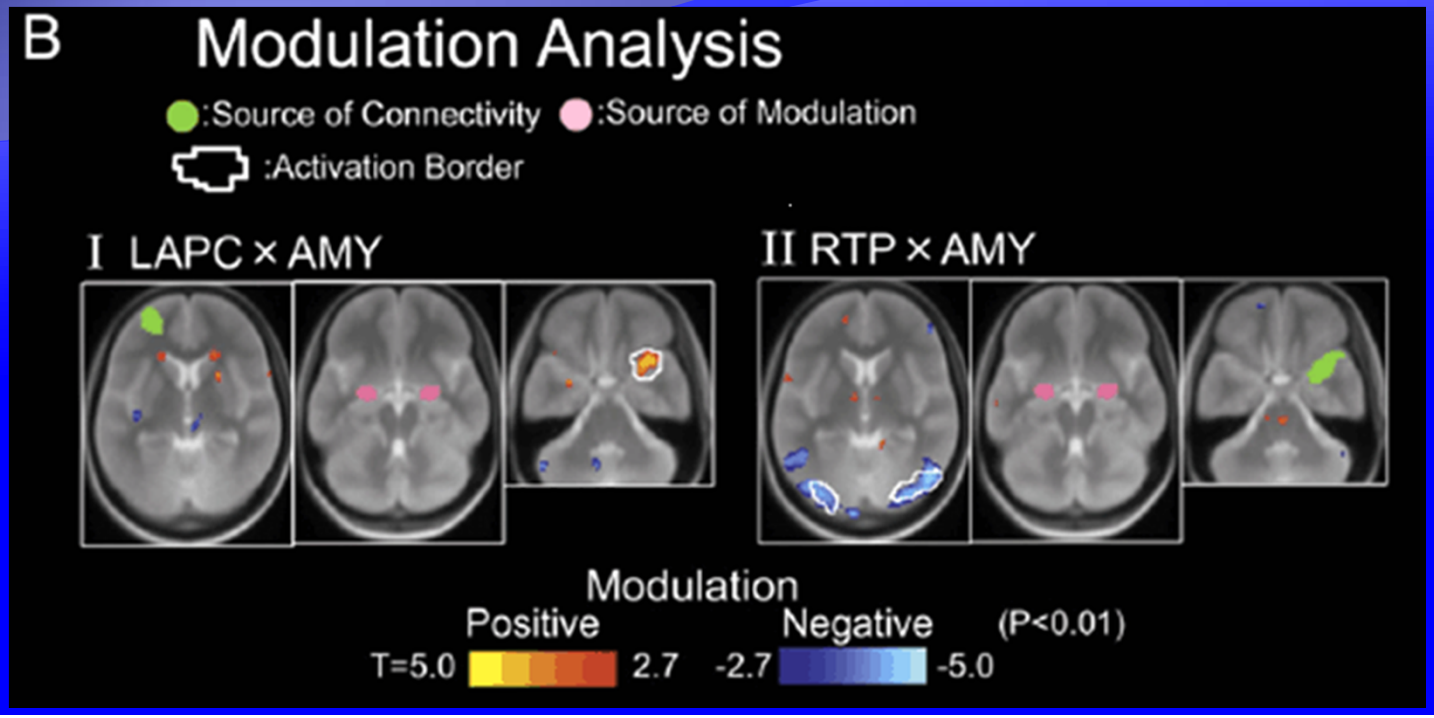




- fMRI study responses to inkblot test
  - [unique – frequent]: temporal pole ($p<0.05$ corr), cingulate & orbitofrontal ($p< 0.001$ unc).
  - [frequent – unique]: occipitotemporal cortex
  - No amygdala responses (even when transient activity examined)
  - Temporal pole heavily connected to amygdala, and may access emotionally valent representations

Asari et al., Neuroimage, 2008

Physiophysiological interaction



$$X_i = X_{AMY} \times X_{LAP} \cdot \beta_{interaction} + X_{LAP} \cdot \beta_{connectivity} + R \cdot \beta_{no_interest} + e_i,$$

- Temporal pole may link sensory input from occipitotemporal regions with top-down frontal control and emotional modulation by the amygdala

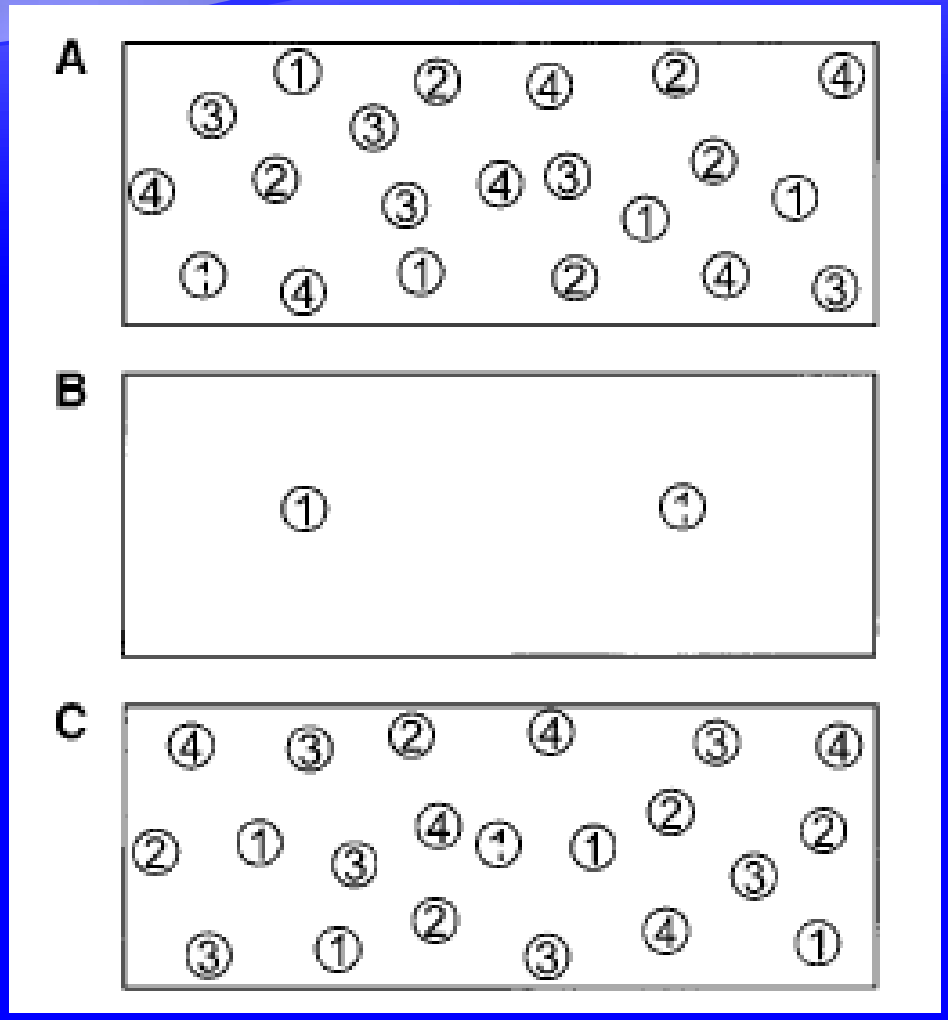
Asari et al., Neuroimage, 2010

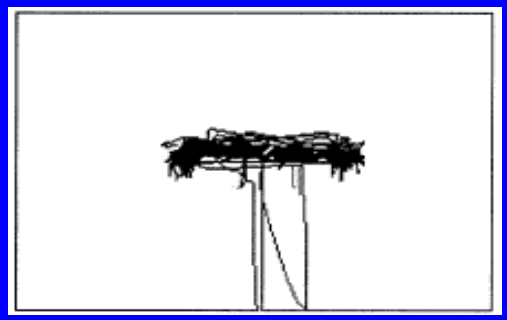
PPI of the superior colliculus

Explore

Saccade

Central

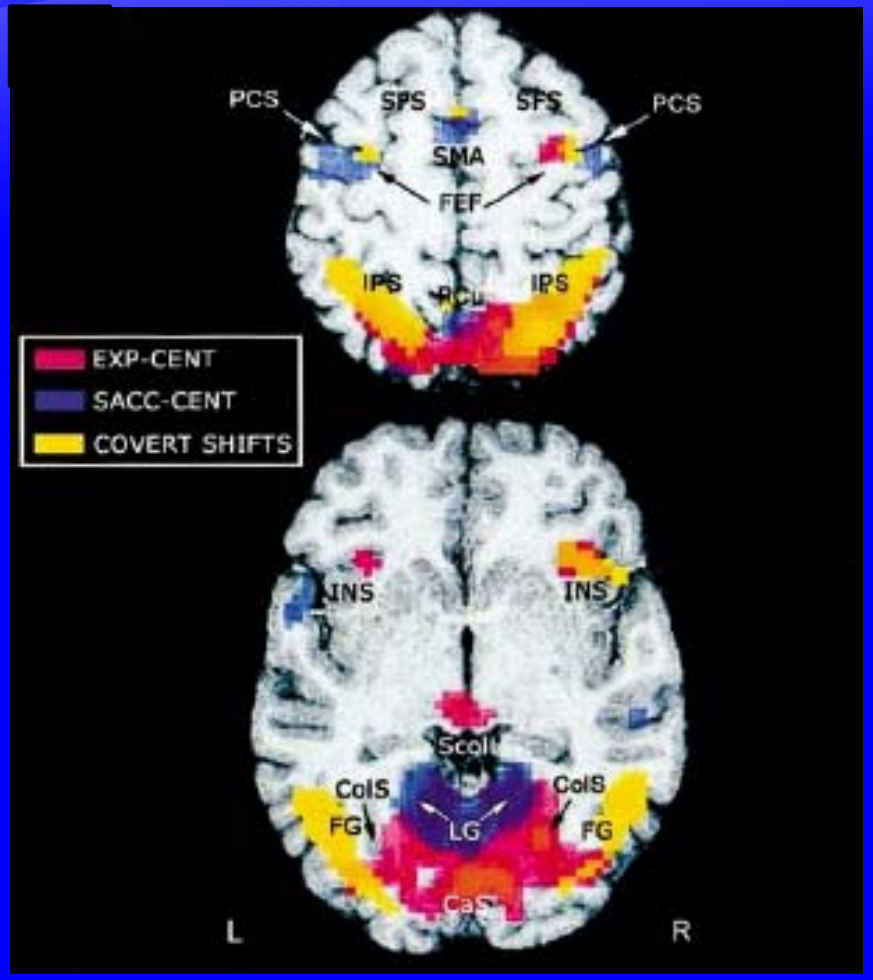




D. Gitelman

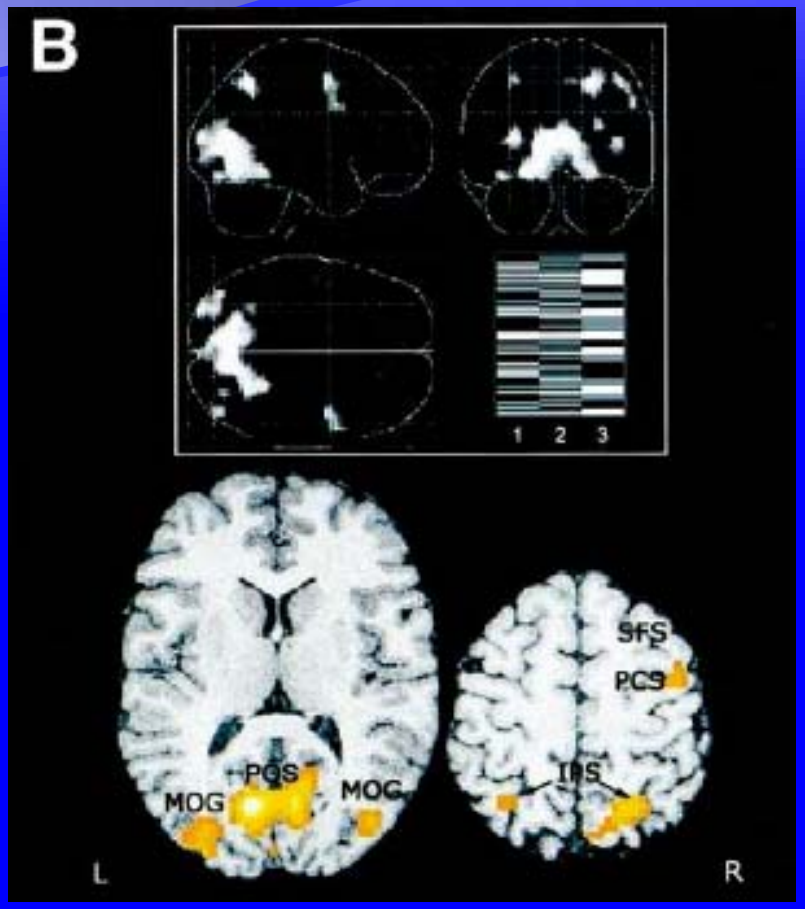
Gitelman et al., Neuroimage, 2002

SPM analysis



Gitelman et al., Neuroimage, 2002

PPI analysis



Areas showing connectivity with the superior colliculus under the explore but not the saccade condition

Gitelman et al., Neuroimage, 2002

Pros & Cons of PPIs

- Pros:
  - Given a single source region, we can test for its context-dependent connectivity across the entire brain
  - Simple to perform
- Cons:
  - Very simplistic model: only allows modelling contributions from a single area
  - Ignores time-series properties of data (can do PPI's on PET and fMRI data)
    - Inputs are not modelled explicitly
    - Interactions are instantaneous

Pros & Cons of PPIs

- Non-factorial PPI's are inefficient
  - PPI term and P (psychological variable) are highly correlated (o.86) in the matrix shown below. This will reduce the sensitivity for estimating the PPI effect (based on attention to motion dataset)

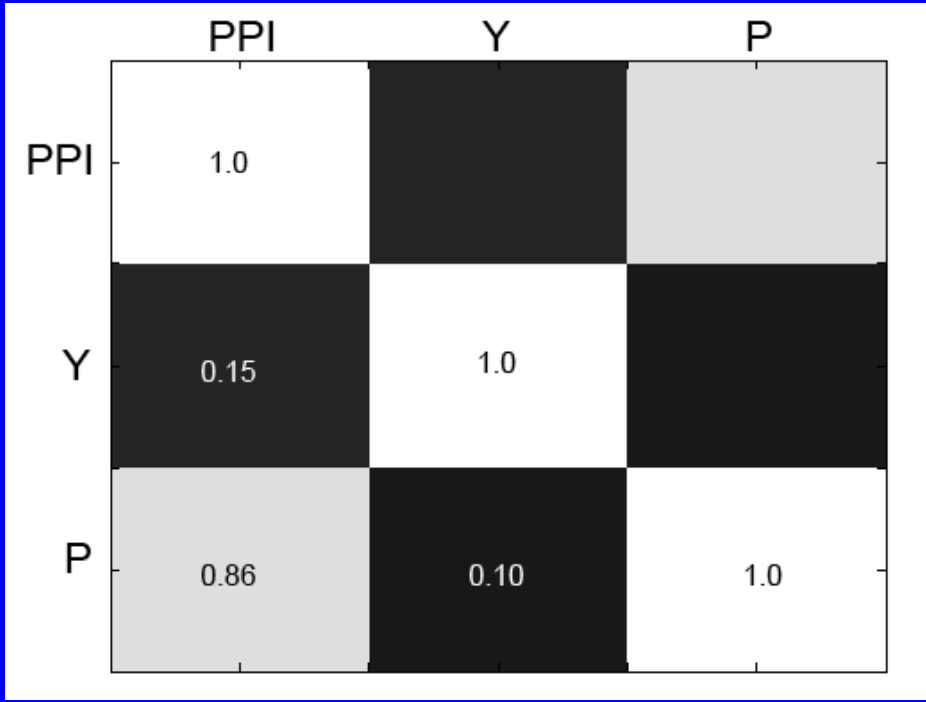


Table of correlations between regressors

gPPI

- See the paper: McLaren, D.G., Ries, M.L., Xu, G., Johnson, S.C., 2012. A generalized form of context-dependent psychophysiological interactions (gPPI): a comparison to standard approaches. NeuroImage 61, 1277-1286.

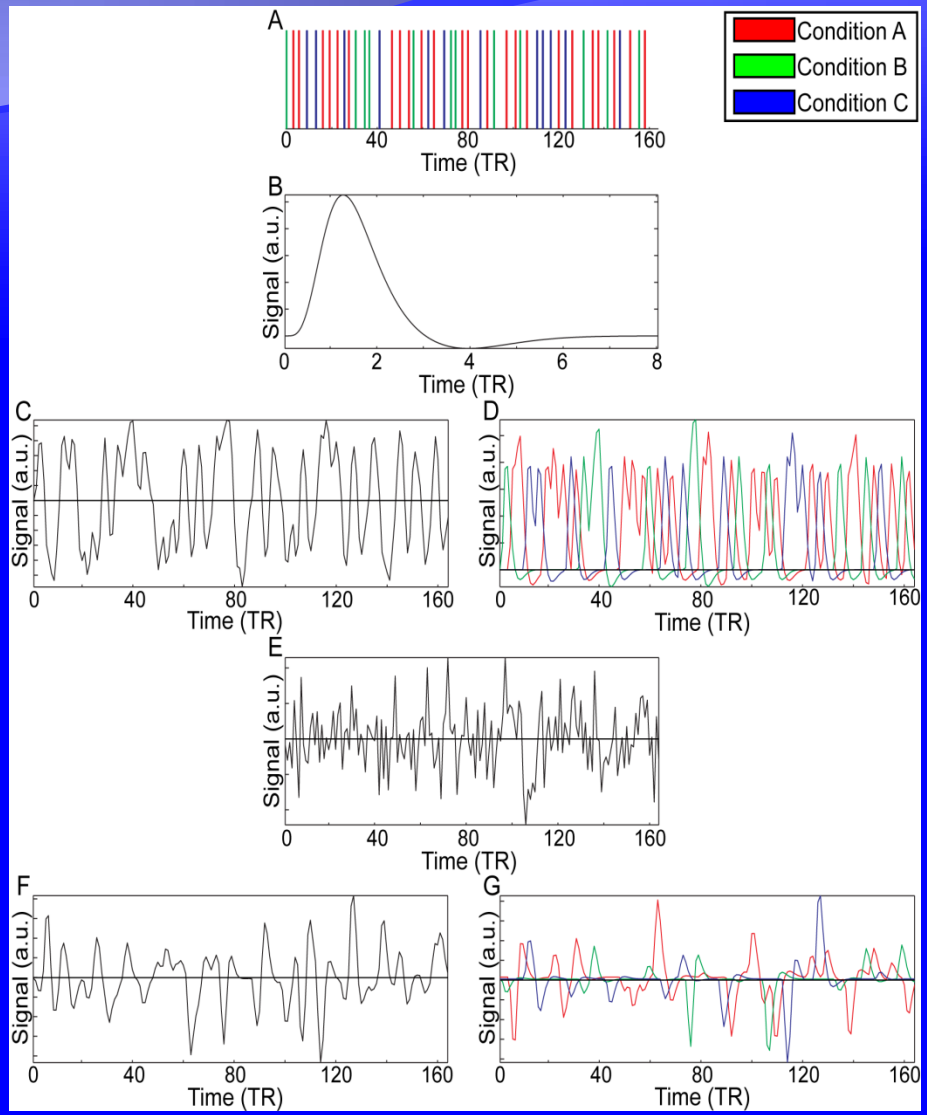
- NITRC.ORG site: https://www.nitrc.org/projects/gppi

gPPI vs. SPM-PPI

Psychological regressor

Regional signal

PPI



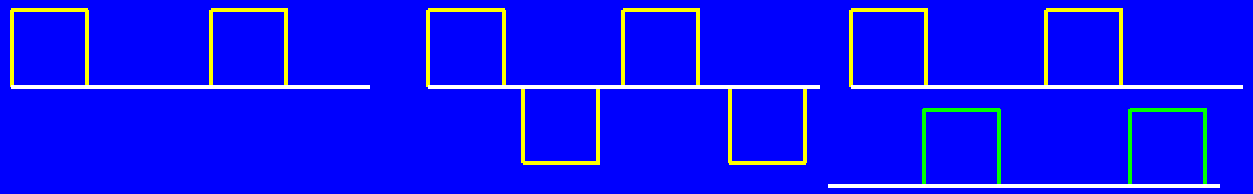
D. Gitelman

D. McLaren, Neuroimage, 2012

1 Condition vs 2 Conditions (same data)

Beta Estimates

	SPM-PPI	SPM-PPI 2 conditions	gPPI
A [-fix] (1 condition)	.9876	--	.9876
A-B (2 conditions)	--	.8675	.9889



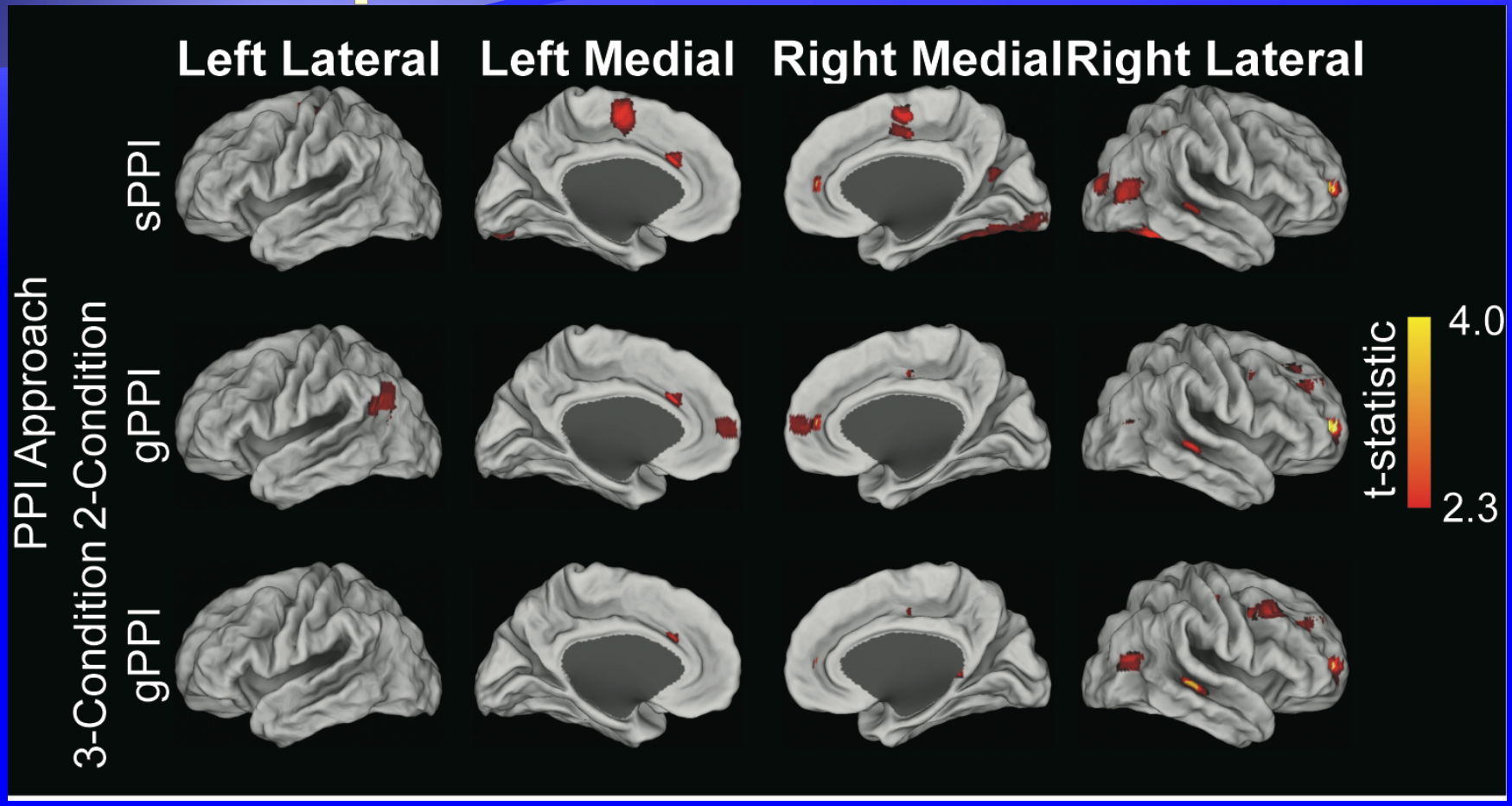
Sums of Squares

	SPM-PPI 1 condition	SPM-PPI 2 conditions	gPPI
A [-fix] (1 condition)	3.6676	--	3.6676
A-B (2 conditions)	--	6.4581	3.5447

D. Gitelman

D. McLaren, personal communication

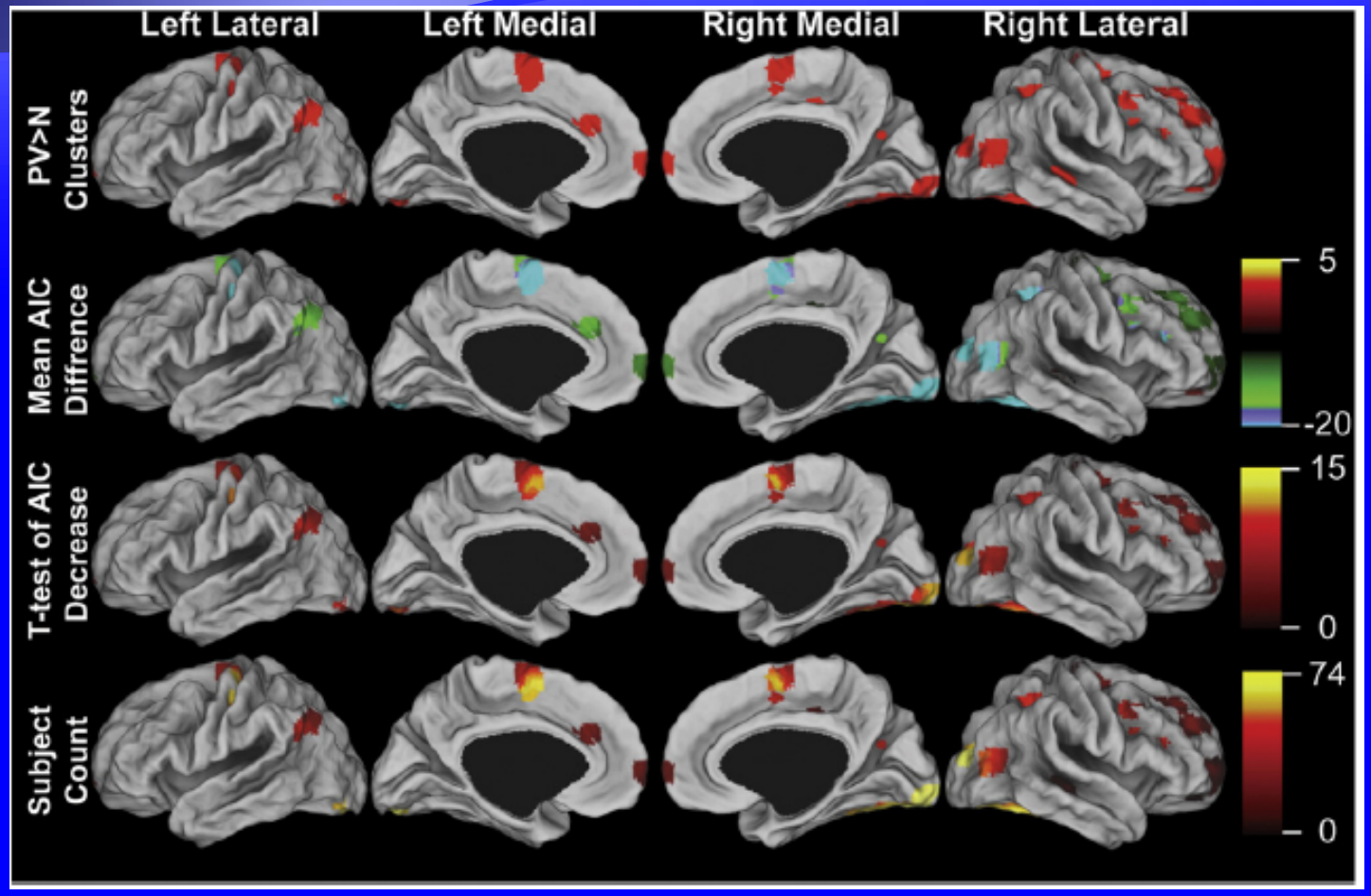
PPI Maps



D. Gitelman

D. McLaren, Neuroimage, 2012

Comparison of sPPI & gPPI



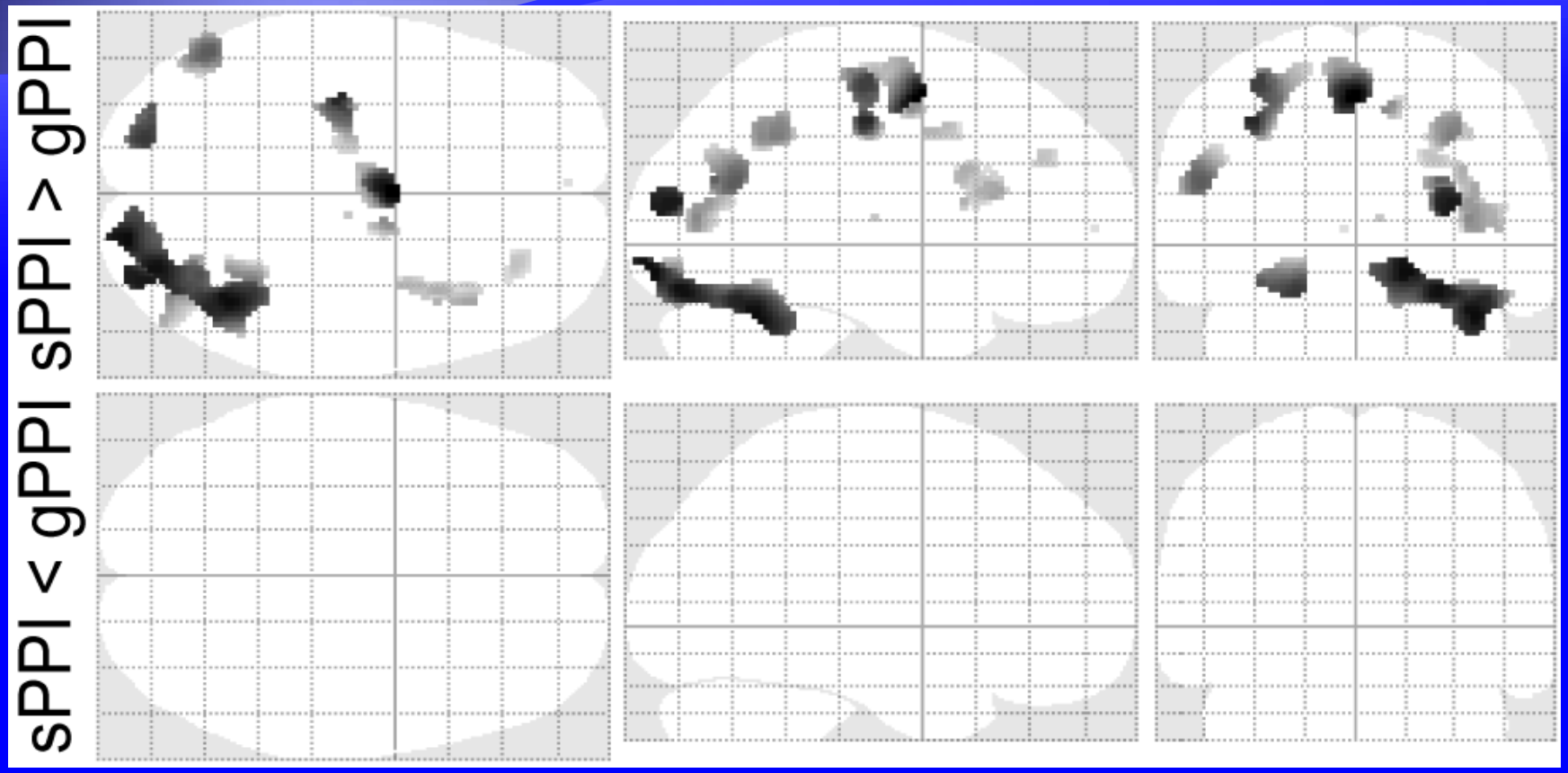
$$AIC = 2k + n\left[\log\left(\frac{RSS}{n}\right)\right]$$

k = # regressors
n = # timepoints
RSS = residual sum of squares

D. Gitelman

D. McLaren, Neuroimage, 2012

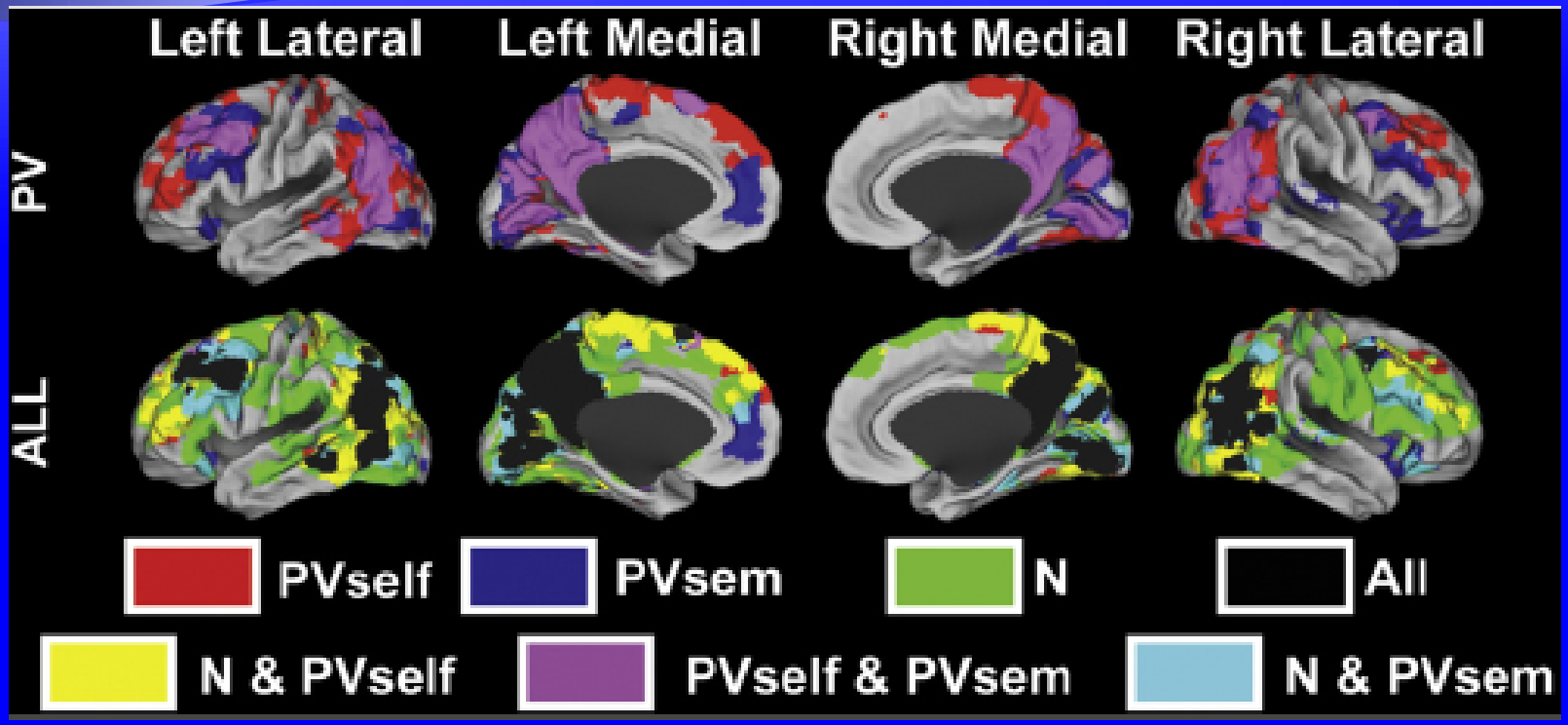
Comparison of sPPI & gPPI



Plot of AIC: Lower is better

D. McLaren, Neuroimage, 2012

gPPI allows conjunctions



D. Gitelman

D. McLaren, Neuroimage, 2012

PPI Additional Questions

- Including main effects in my PPI analysis takes away all the interaction results. Do I have to include main effects?
  - Absolutely! Otherwise, the inference on interactions will be confounded by main effects.
- Should I include movement regressors in my PPI analysis?
  - Yes, include any nuisance effects you would normally include.

PPI Additional Questions

- What does it mean to adjust for different effects?
  - Adjusting for effects means keeping effects of interest and removing effects of no interest, e.g., movement regressors, block effects, etc.
  - In order to adjust an effects of interest F-contrast should be set up before trying to extract the data.

PPI Additional Questions

- Should VOIs be based on the exact locations of group effects or should they be subject specific?
  - Both. VOI s should be subject specific, but should be "close enough" to a maxima based on a group analysis, the literature , etc. "Close enough" depends on where the maxima is in the brain, the smoothness of the data, etc. Close enough in the caudate might be 5 mm, while in the parietal cortex, close enough might be 1 cm.

PPI Additional Questions

- How do I select regions that are "close enough" to a maxima?
  - Display a contrast that shows the regions of interest.
  - Move the SPM cursor to the group maxima.
  - Right click in the graphics window next to the glass brain. The cursor will jump to the closest maxima, and the number of mm it moves will be recorded in the Matlab window. Make a note of how far the cursor moves.
  - Now click eigenvariate and extract as usual
- How big should the VOIs be?
  - This depends on the smoothness of the data and the region. If you have high resolution data or are in a subcortical nucleus you probably want a smaller sphere. Generally between 4 and 8 mm radius spheres are used.

PPI Additional Questions

- How is a group PPI analysis done?
  - The con images from the interaction term can be brought to a standard second level analysis (one-sample t-test within a group, two-sample t-test between groups, ANOVA's, etc.)
- Can I run a PPI based on a single main effect?
  - Yes, but this is not an optimal design. It is important to realize that the interaction term will be very highly correlated with the main effect regressor, resulting in very low power for detecting the interaction effect.

PPI Analysis: Practical

PPI analysis: overview

- Run a standard GLM analysis
  - Include conditions and any nuisance effects (motion, etc.)
  - For ease of analysis combine multiple sessions into a single session and include block effects
- Display contrast of interest
- Extract VOI (volume of interest), adjusting for effects of interest (i.e., exclude any nuisance regressors)
- PPI button (makes PPI regressors)
  - SPM.mat file from standard GLM analysis
  - Setup contrast of Psych conditions

PPI analysis: overview

- Run PPI – GLM analysis
  - PPI.ppi (interaction)
  - PPI.Y (main effect: source region BOLD data)
  - PPI.P (main effect: Psych conditions that formed PPI)
- Contrast is [1 0 0] for positive effect of interaction and [-1 0 0] for negative effect (assuming conditions entered in order listed)

Standard GLM: design setup and estimation

- The analysis directory should include:
  - Directory named functional which includes the preprocessed fMRI volumes
  - Directory name structural, which includes a T1 image
  - Files: factors.mat, block_regressors.mat, multi_condition.mat and multi_block_regressors.mat
  - Make 3 empty directories called GLM, PPI-V2 and PPI-V5

Standard GLM: design setup and estimation

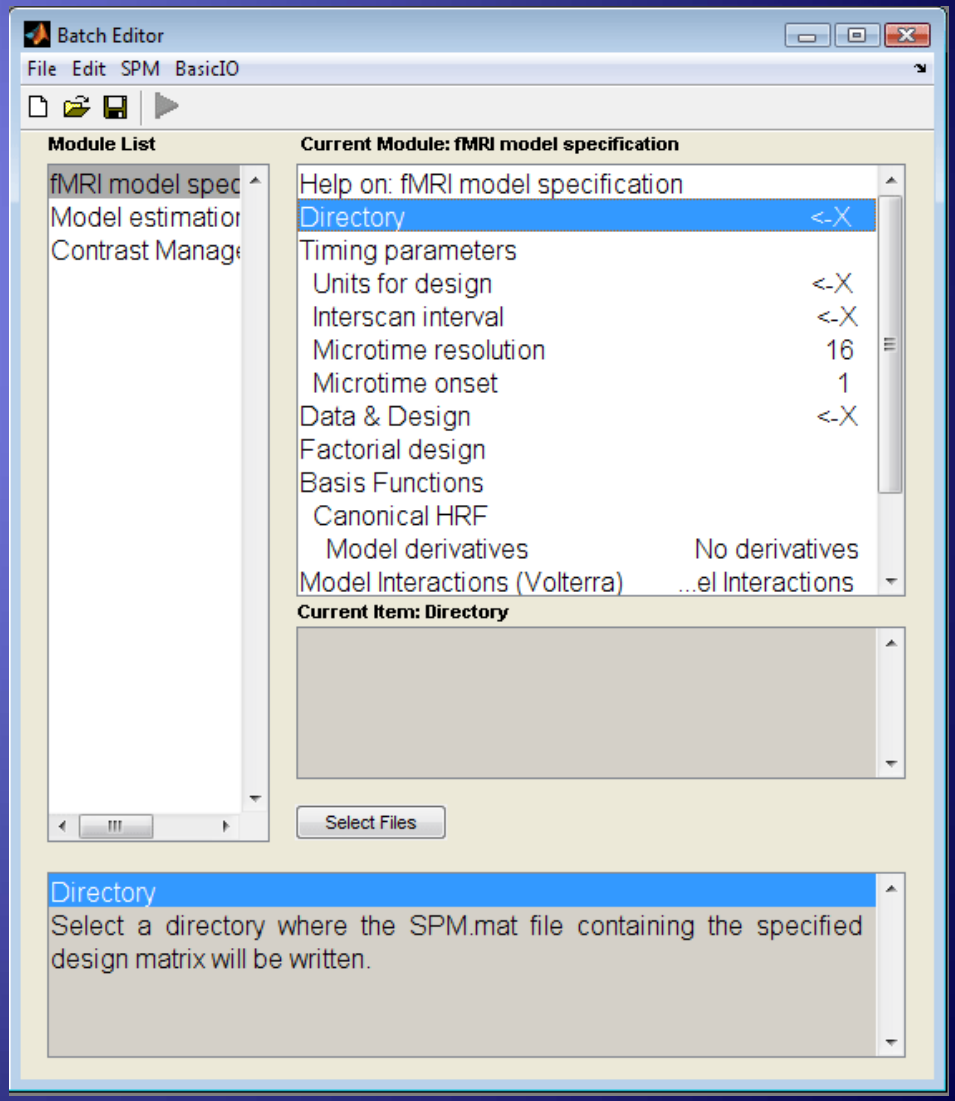
- From Matlab command prompt
  - >> cd 'path-to-analysis-directory'
  - *Make sure SPM12 is in the Matlab path*
  - *Start SPM: spm*

  - From the Tasks menu at the top of the Graphics window choose Batch

Standard GLM: Batch window

- From the SPM menu in the batch window, select stats then select:

- fMRI model specification
- Model estimation
- Contrast Manager



Standard GLM: Design setup

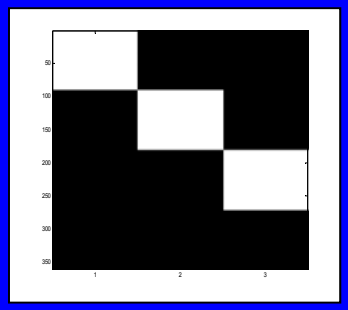
- Directory: choose the GLM directory
- Units for designs: scans
- Interscan interval: 3.22
- Click Data & Design then New: Subject/Session
- Scans: choose the functional scans
- We will add the conditions using multiple condition and regressor files. The files are called:
  - Multiple conditions: multi_condition.mat
  - Multiple regressors: multi_block_regressors.mat

Multiple condition file

- To look at the file (not necessary for the analysis, but just for didactic purposes)
  - >> load multi_condition.mat
  - Then type names or onsets or duration in the Matlab command window.
- Contains 3 cell arrays of the same size (not all entries are shown below)
  - names
    - names{1} = 'Stationary';
    - names{2} = 'No attention';
  - onsets
    - onsets{1} = [80 170 260 350];
  - durations
    - durations{1} = 10; (can be just a single number if all events have the same duration)

Multiple regressor file

- To look at the file (not necessary for the analysis, but just for didactic purposes)
  - >> load multi_block_regressor.mat
- The file contains a variable R., which is an N x M matrix
  - N = number of scans
  - M = number of regressors
- Block regressors model different sessions. Use this command to set up. Can also use various combinations of zeros and ones functions.
  - >> R = kron(eye(3),ones(90,1));zeros(90,3)]) ; or
  - >> R = [blkdiag(ones(90,1),ones(90,1),ones(90,1));zeros(90,3)];



Standard GLM: Design setup

- High-Pass Filter : 192
  - Note: most designs will use a high-pass filter value of 128. This dataset requires a longer high-pass filter in order not to lose the low frequency components of the design.
- The default values on the rest of the entries are correct
- Click Model Estimation → Select SPM.mat → Click Dependency and choose fMRI model specification: SPM.mat File

Standard GLM: Contrast setup

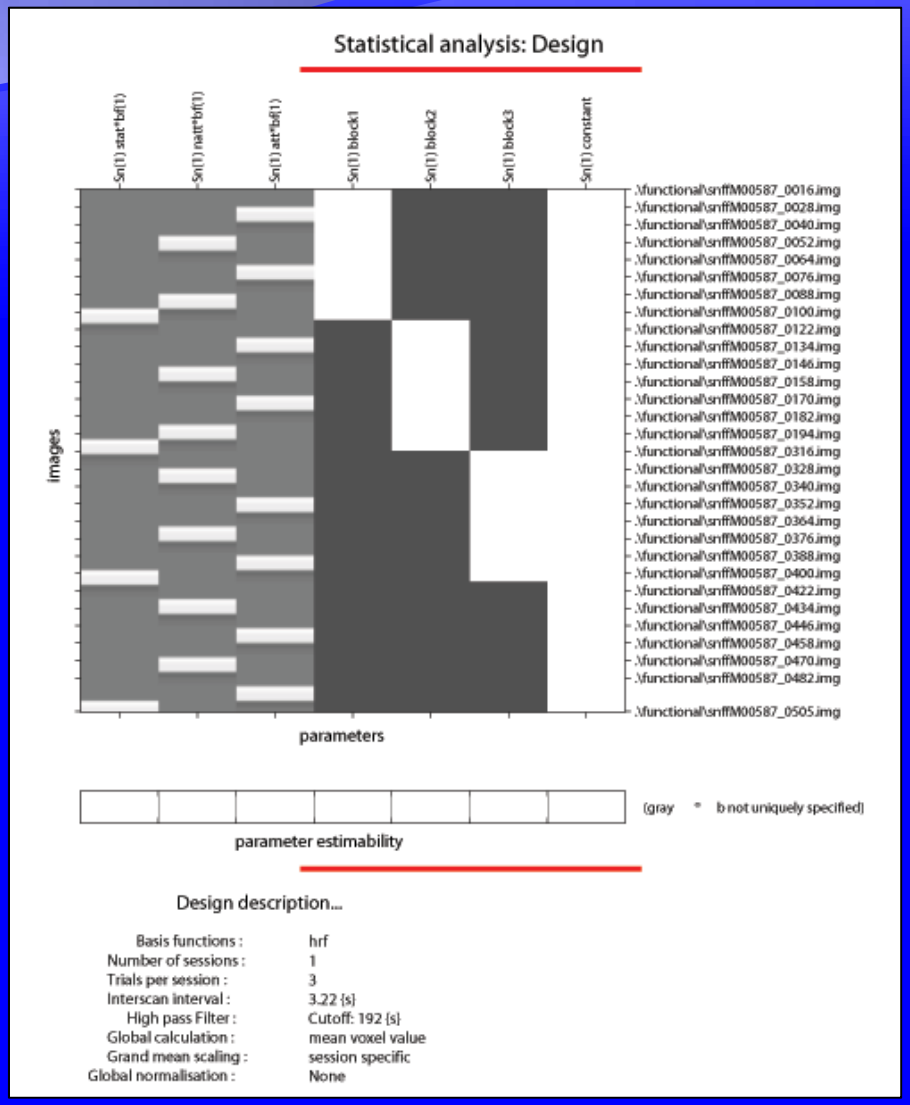
- Contrast manager
  - Select SPM.mat → Click Dependency and choose Model estimation: SPM.mat file
  - Contrast Sessions
    - New F-Contrast
      - Name: Effects of interest
      - Weights matrix : eye(3)

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

Standard GLM: Contrast setup

- Contrast Sessions
  - New T-Contrast
    - Name: Attention
    - Weights vector: [0 -1 1]
  - New T-Contrast
    - Name: Motion
    - T contrast vector: [-2 1 1]
- Click Save button and save the batch file
- Click Run button (green arrow)

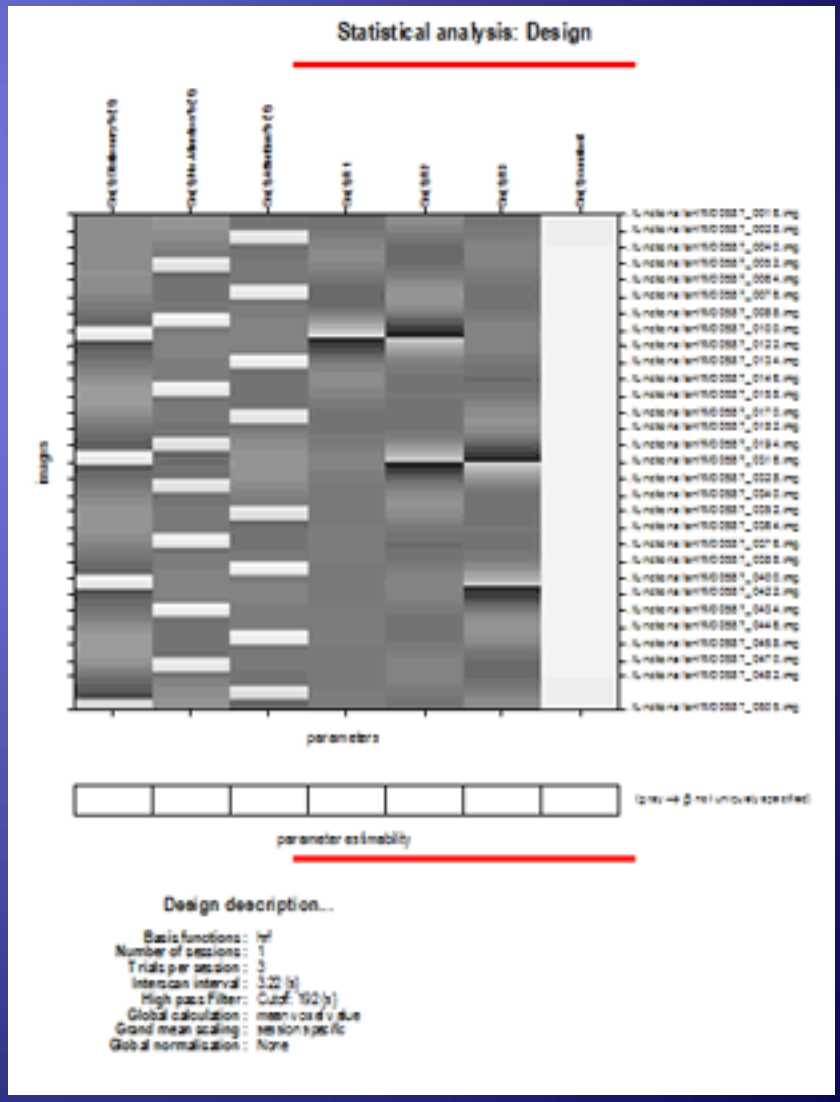
Design matrix: pre-estimation



D. Gitelman

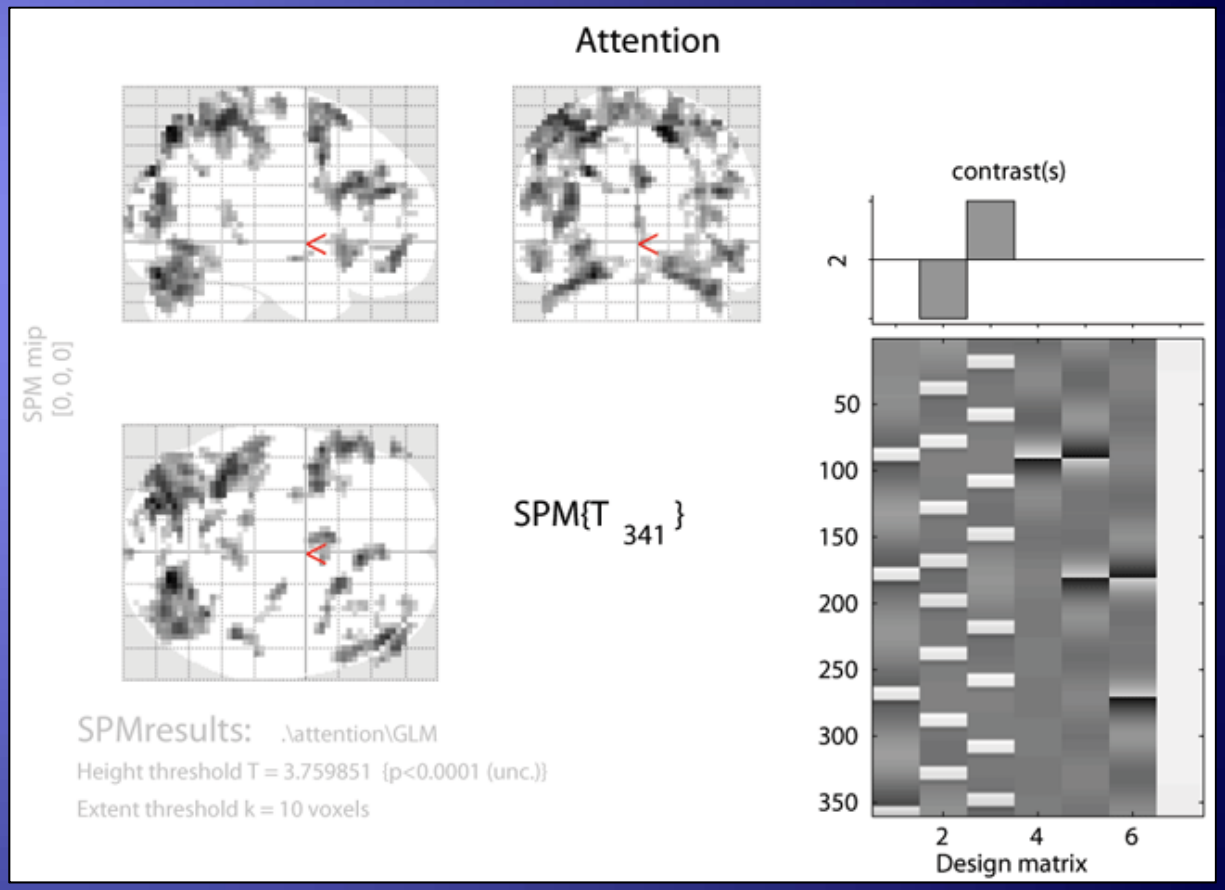
Design matrix: post-estimation

The change in the design matrix compared with the previous slide is due to non-sphericity effects.



Attention contrast

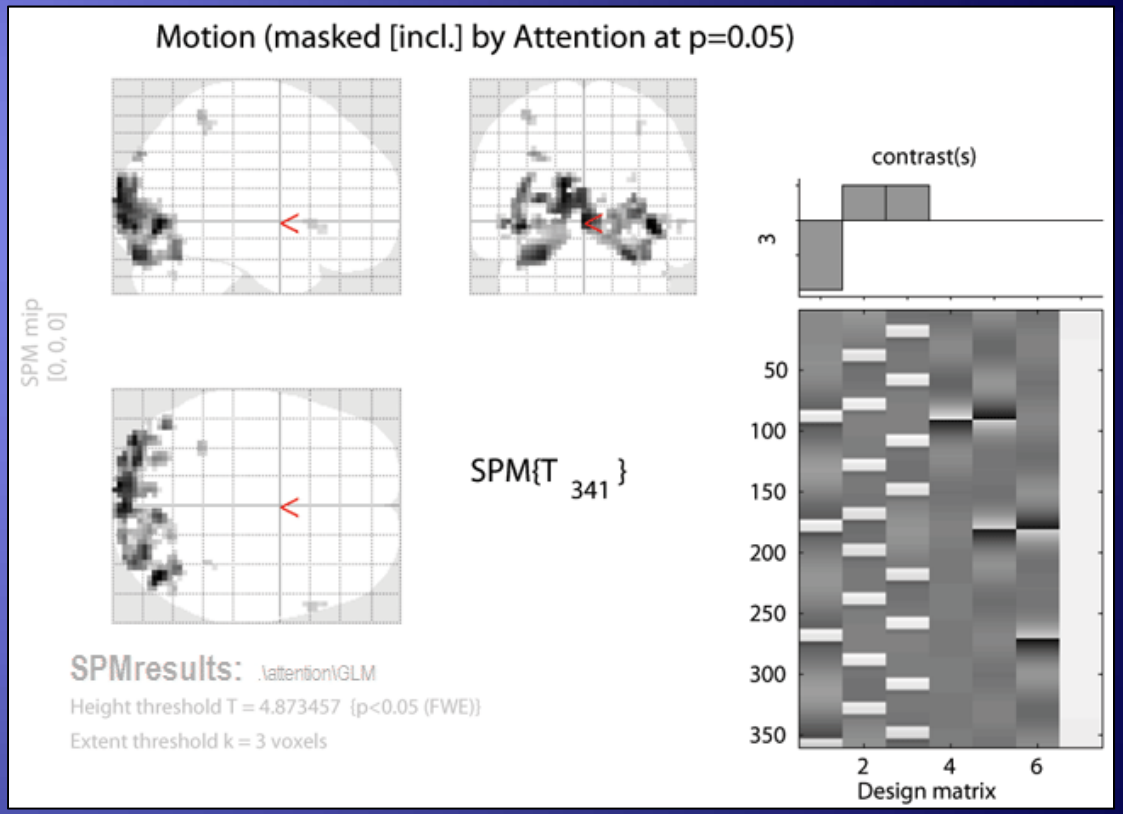
- Click Results
- Select SPM.mat
- Choose Attention contrast
- Apply Masking: None
- p value adjust: None
- Threshold p: 0.0001
- & extent threshold: 10



Motion masked by Attn-noAttn

- Click Results
- Select SPM.mat
- Choose Motion contrast
- Apply Masking: contrast
- Select Mask: Attention
- Uncorrected mask p: 0.01
- Nature of mask: inclusive
- p value adjust: FWE
- Threshold p: 0.05
- & extent threshold: 3

- Example of a psychological interaction

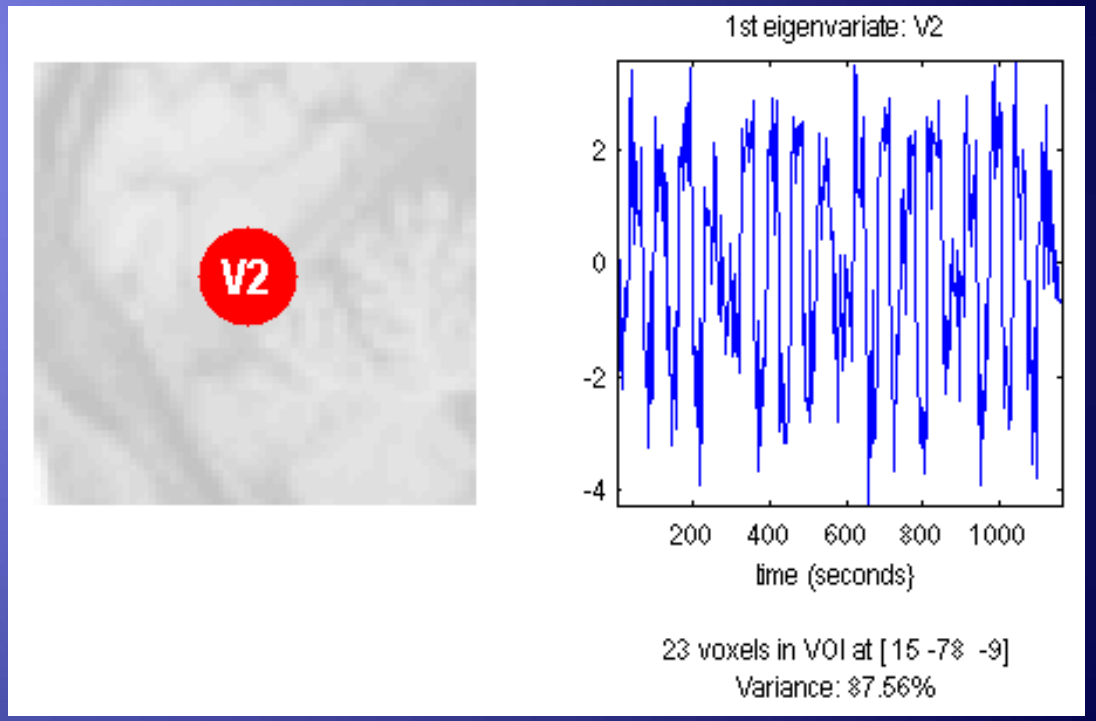


PPI $V_2 \rightarrow V_5$

Extracting VOI: V2 → V5

- Results → Choose SPM.mat → Motion contrast
- Apply Masking: none
- p-value adjustment: FWE
- threshold T or p value: 0.05
- & extent threshold voxels: 3
- Go to point [15 -78 -9]
- Click eigenvariate
- Name of region: V2
- Adjust for: Effects of Interest
- ROI definition: sphere
- Sphere radius (mm): 6

- (The VOI file is saved to the GLM directory.)

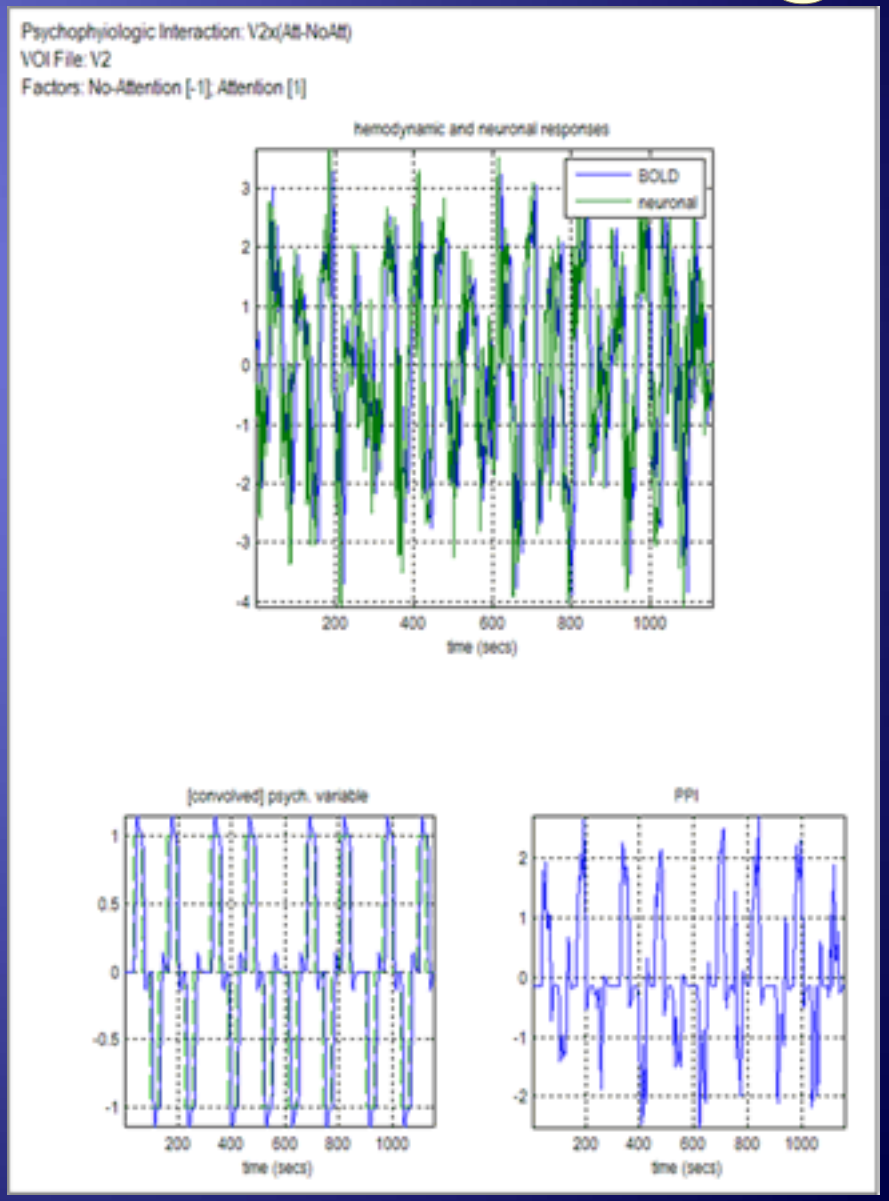


Create PPI variable: V2 → V5

- Click PPI button
- Select SPM.mat in the GLM directory.
- Analysis type: PPI

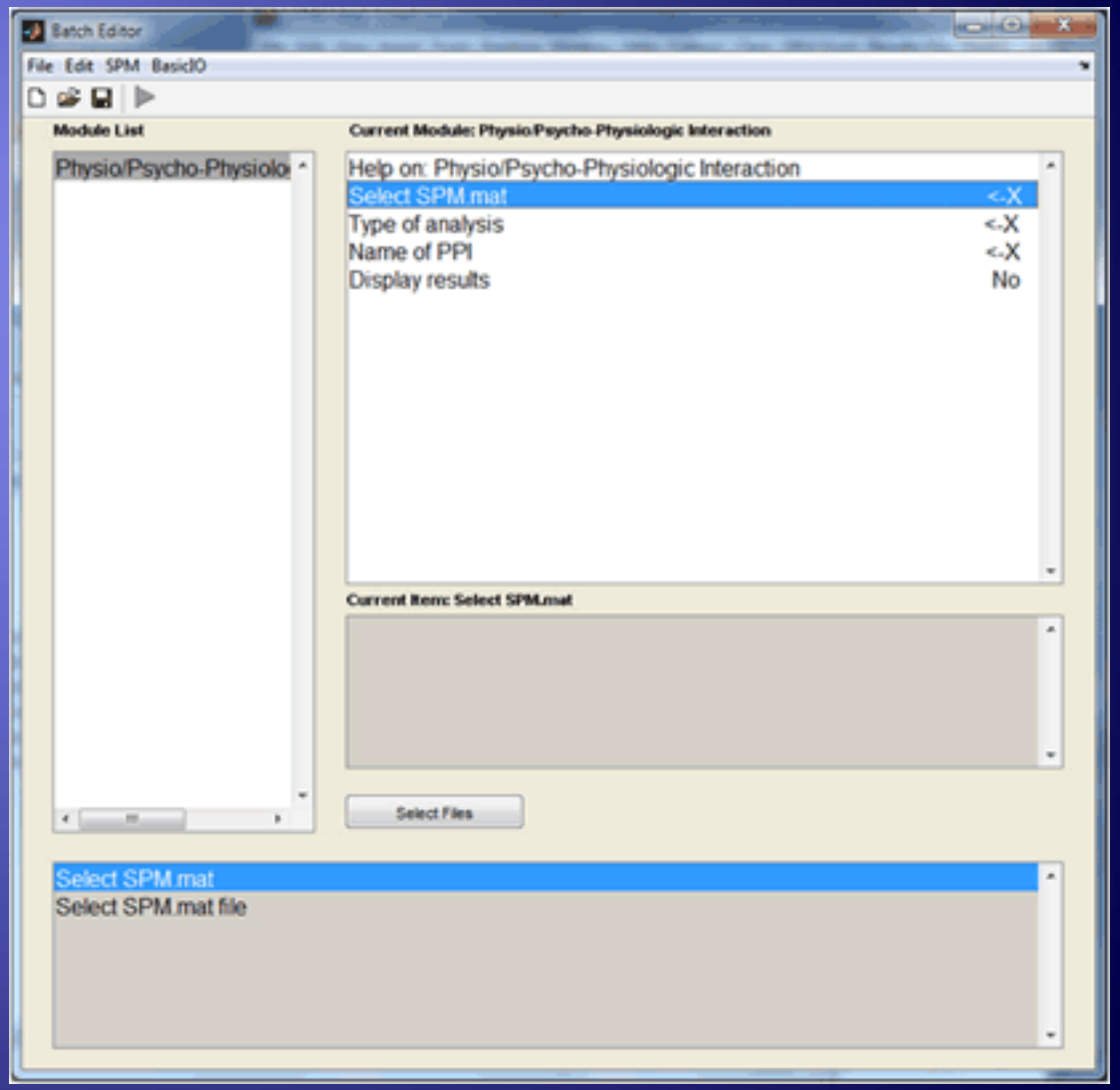
- Select VOI_V2_1.mat
- Include Stationary: No
- Include No-Attention: Yes
- Contrast weight: -1
- Include Attention: Yes
- Contrast weight: 1
- Name of PPI: V2x(Att-NoAtt)

- (The PPI file is automatically saved to the GLM directory.



PPI batch: 1

- Open batch window
- From the SPM menu select Stats-> Physio/ Psycho-physiologic Interaction
- For SPM.mat select the one in the GLM folder
- Type of analysis : Psycho-physiologic Interaction

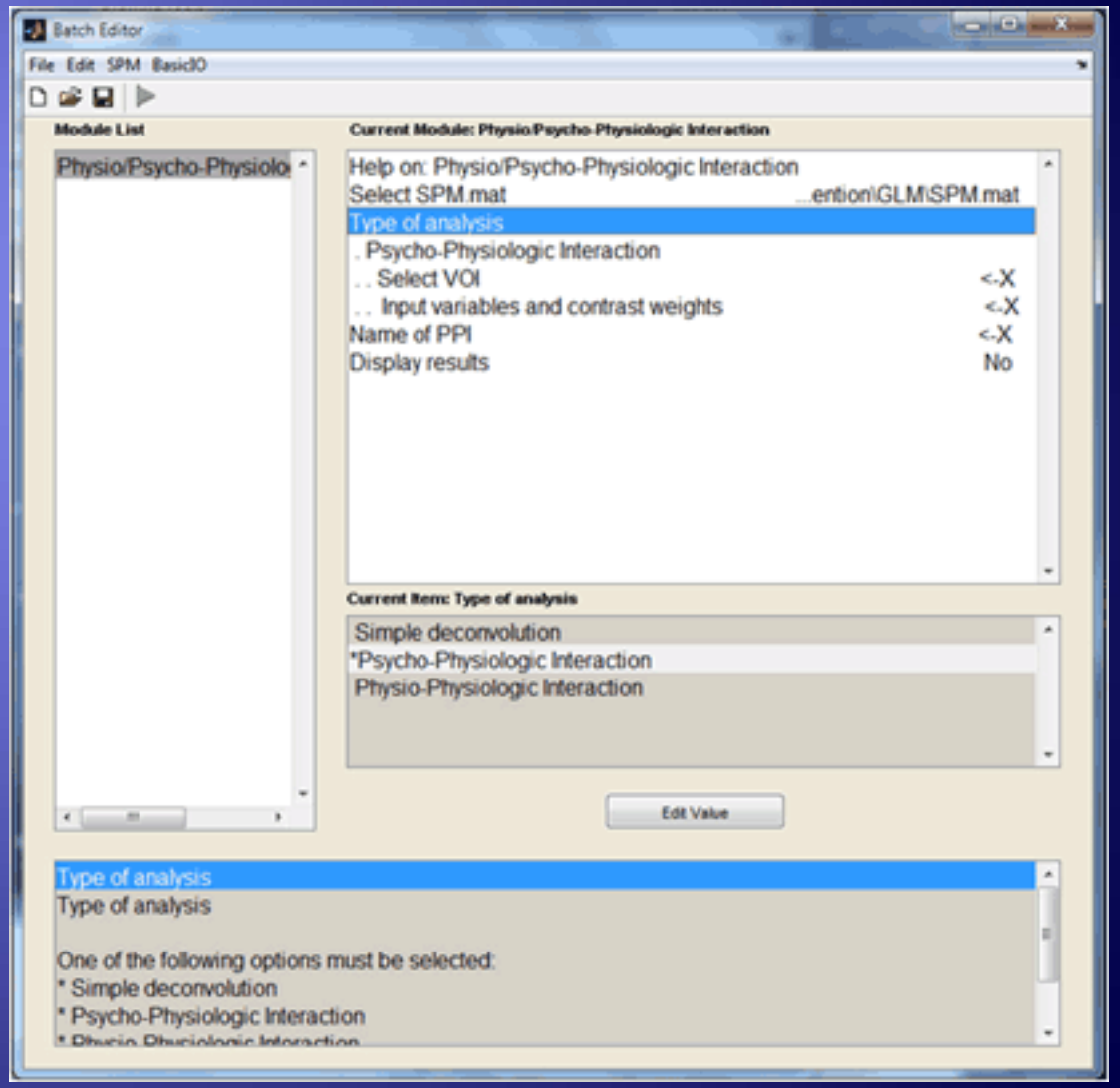


PPI batch: 2

- Type of analysis : Psycho-physiologic Interaction
- VOI: choose the V2 VOI
- Input variables and contrast weights

$$\begin{bmatrix} 2 & 1 & -1 \\ 3 & 1 & 1 \end{bmatrix}$$

- Column 1 is the condition (see SPM.Sess.U), column 2 will usually be 1, column 3 is the contrast weight.
- Name of PPI: : V2x(Att-NoAtt)
- Save the batch file
- Run the batch file



PPI - GLM analysis: V2 → V5

- cd to the GLM directory.
  - >> load PPI_V2x(Att-NoAtt)
  - This must be done before setting up the PPI-GLM so the variables are in the Matlab workspace.
- From the tasks menu at the top of the Graphics window choose Batch
- Select
  - fMRI model specification
  - Model estimation
  - Contrast Manager

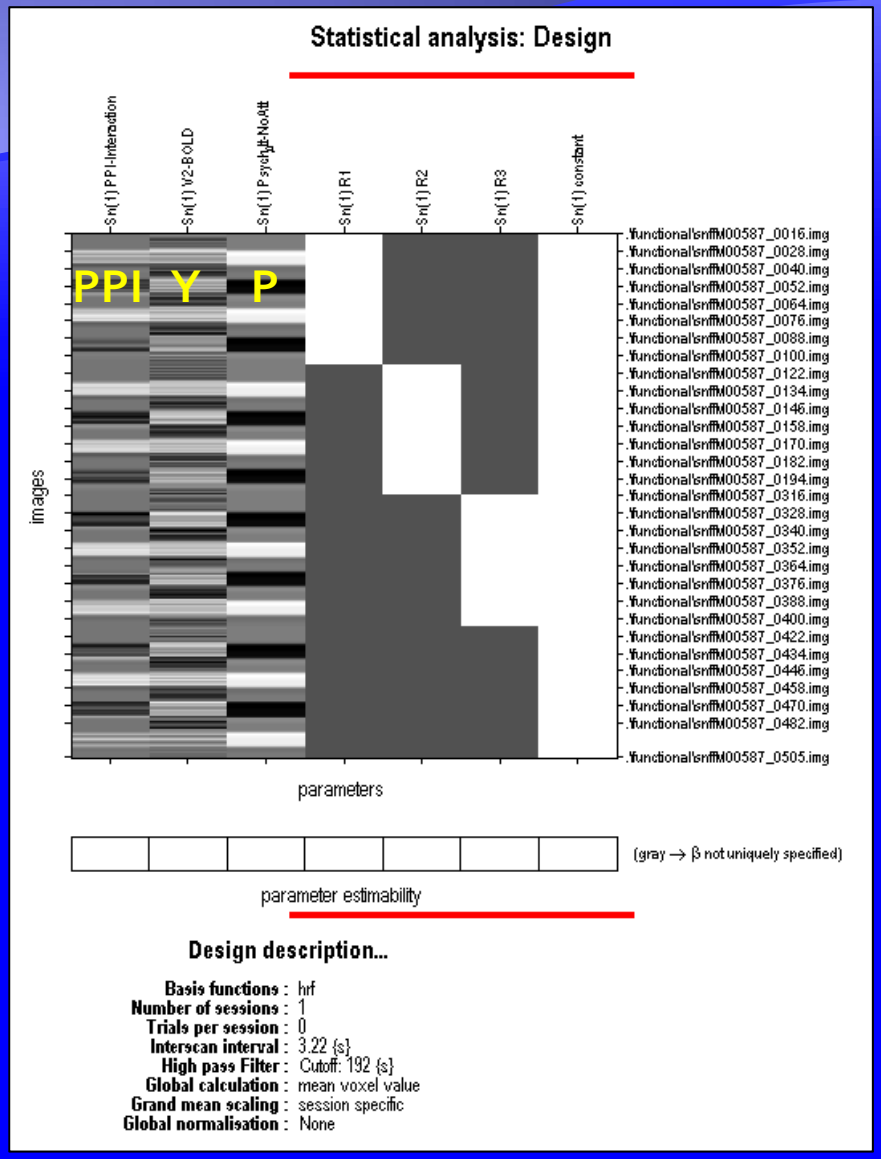
PPI - GLM analysis: V2 → V5

- Directory: choose the PPI-V2 directory
- Units for design: scans (actually doesn't matter in this case since we use only regressors).
- Interscan interval : 3.22
- Add a New subject/session
- Scans: choose the fMRI scans
- Click Regressors and add 3 regressors
  - Regressor 1: Name: PPI-interaction, Value: PPI
  - Regressor 2: Name: V2-BOLD, Value: Y
  - Regressor 3: Name: Psych_Att-NoAtt, Value: P

PPI – GLM analysis: V2 → V5

- Click Multiple regressors and choose the multi_block_regressor.mat file
- High Pass Filter: 192
- Click Model Estimation → Select SPM.mat → Click Dependency and choose fMRI model specification: SPM.mat File
- Contrast manager
  - Select SPM.mat → Click Dependency and choose Model estimation: SPM.mat File
  - Contrast Sessions
    - New T-Contrast
      - Name: Interaction V2 x (Att-NoAtt)
      - Weights vector: [1]
- Save the batch file
- Run

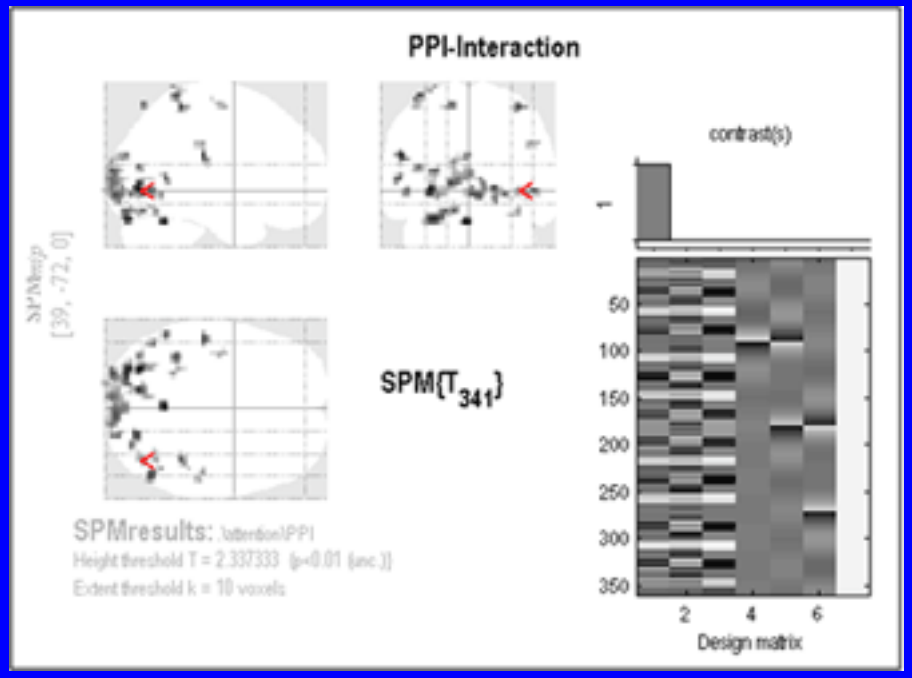
PPI – GLM design: V2 → V5

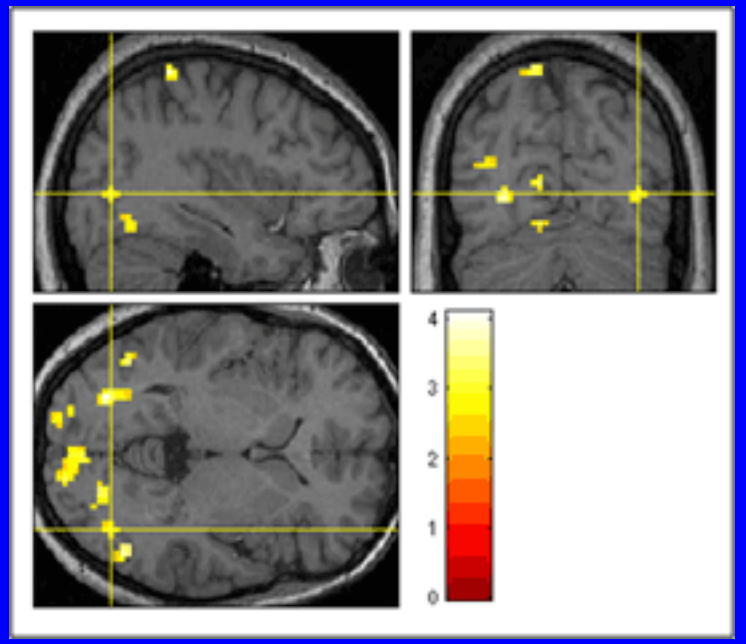


PPI results: V2 →V5

- Click Results
- Select SPM.mat
- Choose PPI contrast
- Apply Masking: None

- Title: Interaction
- p value adjust: None
- Threshold p: 0.005 (was 0.01 in spm8)
- & extent threshold: 3
- Go to V5 (39 -72 0)



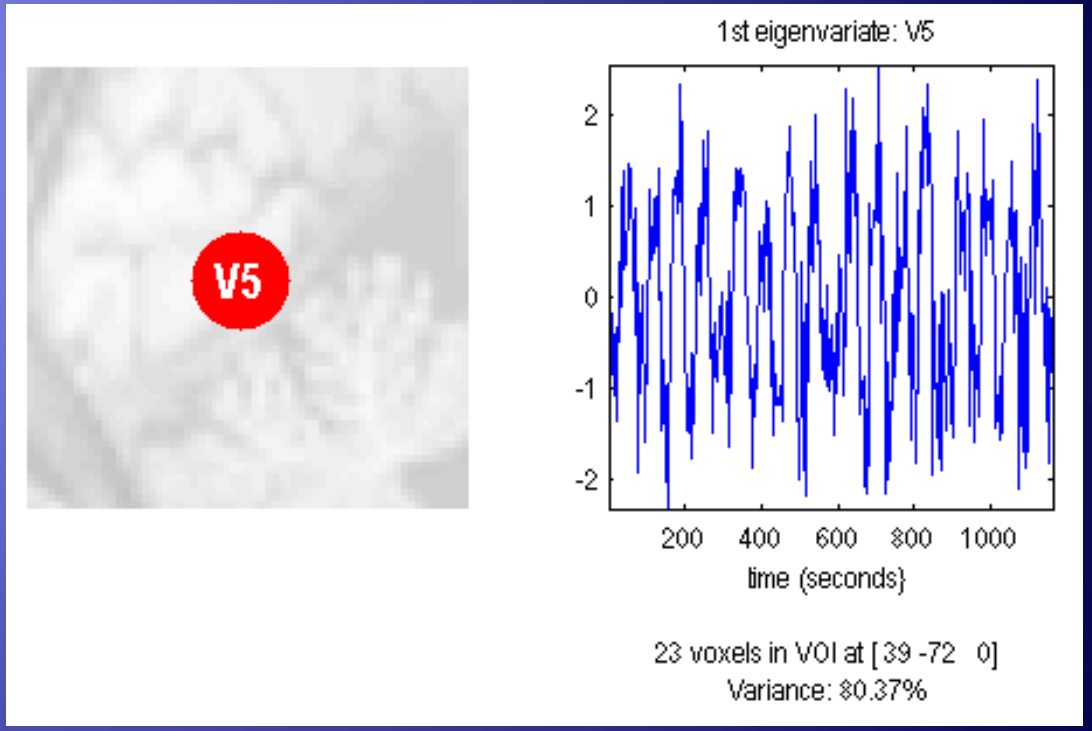


PPI $V_5 \rightarrow V_2$

Extracting VOI: V5 → V2

- Results → Choose SPM.mat → Motion contrast
- Apply Masking: none
- p-value adjustment: FWE
- threshold T or p value: 0.05
- & extent threshold voxels: 3
- Go to point [39 -72 0]
- Click eigenvariate
- Name of region: V5
- Adjust for: Effects of Interest
- ROI definition: sphere
- Sphere radius (mm): 6

- (The VOI file is saved to the GLM directory.)

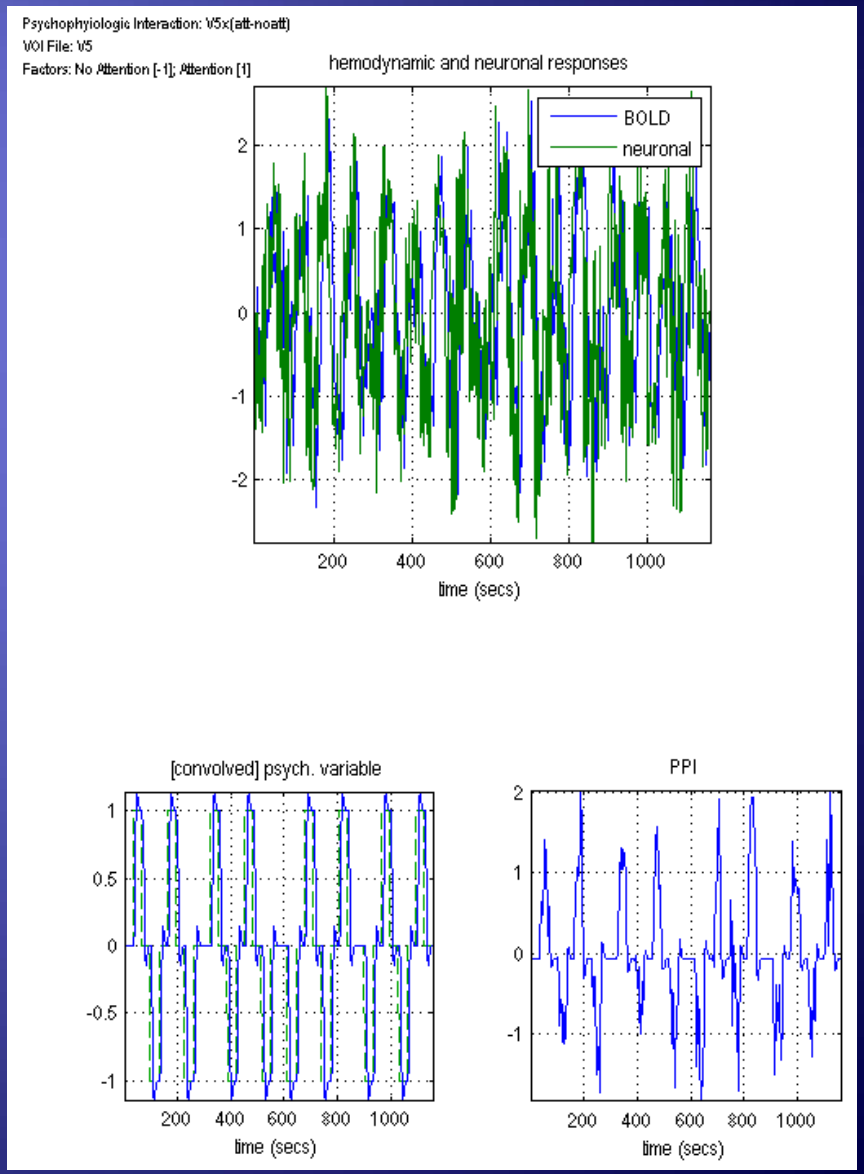


Create PPI variable: V5 → V2

- Click PPI button
- Select SPM.mat in the GLM directory.
- Analysis type: PPI

- Select VOI_V5_1.mat
- Include Stationary: No
- Include No-Attention: Yes
- Contrast weight: -1
- Include Attention: Yes
- Contrast weight: 1
- Name of PPI: V5x(Att-NoAtt)

- (The PPI file is automatically saved to the GLM directory.



PPI - GLM analysis: V5 → V2

- cd to the GLM directory
  - >> load PPI_V5x(Att-NoAtt)
  - This must be done before setting up the PPI-GLM so the variables are in the Matlab workspace.
- From the tasks menu at the top of the Graphics window choose Batch
- Select
  - fMRI model specification
  - Model estimation
  - Contrast Manager

PPI - GLM analysis:: V5 → V2

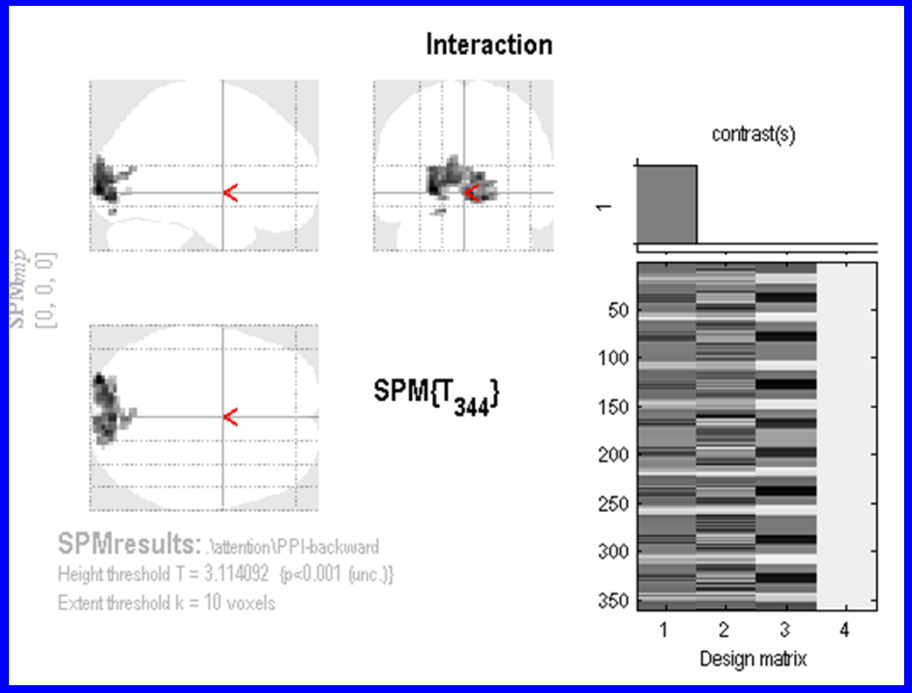
- Directory: choose the PPI-V5 directory
- Units for design: scans (actually doesn't matter in this case since we use only regressors).
- Interscan interval : 3.22
- Add a New subject/session
- Scans: choose the fMRI scans
- Click Regressors and add 3 regressors
  - Regressor 1: Name: PPI-interaction, Value: PPI
  - Regressor 2: Name: V2-BOLD, Value: Y
  - Regressor 3: Name: Psych_Att-NoAtt, Value: P

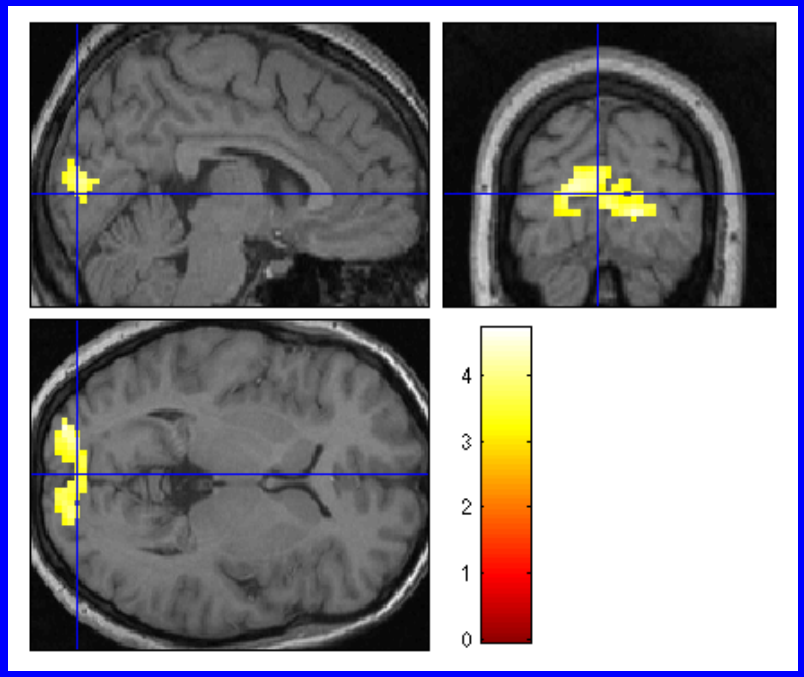
PPI – GLM analysis: V5 → V2

- Click Multiple regressors and choose the multi_block_regressor.mat file
- High Pass Filter: 192
- Click Model Estimation → Select SPM.mat → Click Dependency and choose fMRI model specification: SPM.mat File
- Contrast manager
  - Select SPM.mat → Click Dependency and choose Model estimation: SPM.mat File
  - Contrast Sessions
    - New T-Contrast
      - Name: Interaction (V5 x (Att-NoAtt))
      - Weights vector: [1]
- Save the batch file
- Run

PPI results: V5 →V2

- Click Results
- Select SPM.mat
- Choose PPI contrast
- Apply Masking: None
- Title: Interaction
- p value adjust: None
- Threshold p: 0.001
- & extent threshold: 10





PPI plotting: VOI setup

- If you have run through both the V2 →V5 and the V5→V2 sections you should now have 2 VOI files: VOI_V2_1.mat and VOI_V5_1.mat.
- If you have not run through both sections then go back to either the slides titled: "Extracting VOI:V2→V5" or "Extracting VOI:V5→V2" and create the VOI's

PPI plotting: interaction terms

- Create 4 PPIs (Click PPI button , then choose psychophysiological interaction as the task to perform.)
  - V2xNoAttention (Use the V2 VOI and include No-Attention with a contrast weight of 1, do not include Stationary, Attention) . Save as v2noatt
  - V2xAttention (Use the V2 VOI and include Attention with a contrast weight of 1, do not include Stationary, No-Attention). Save as v2att
  - V5xNoAttention (Use the V5 VOI and include No-Attention with a contrast weight of 1, do not include Stationary, Attention). Save as v5noatt
  - V5xAttention (Use the V5 VOI and include Attention with a contrast weight of 1, do not include Stationary, No-Attention. Save as v5att

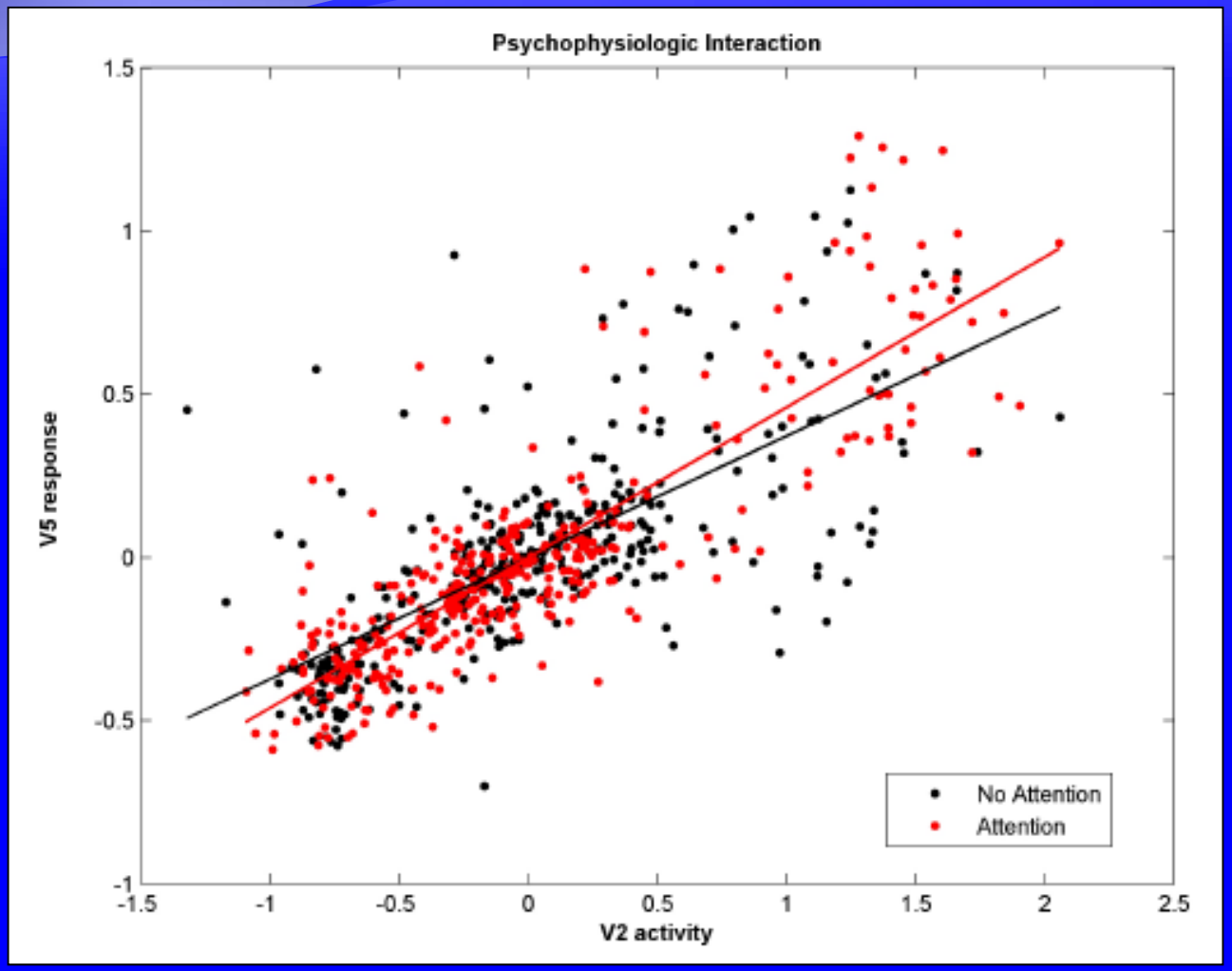
PPI plotting: load PPI's and plot

- Load the PPIs you just created (They will be in the GLM directory.)
  - >> v2noatt = load('PPI_v2noatt.mat');
  - >> v2att = load('PPI_v2att.mat');
  - >> v5noatt = load('PPI_v5noatt.mat');
  - >> v5att = load('PPI_v5att.mat');
- Plot the PPI data points
  - figure
  - plot(v2noatt.PPI.ppi, v5noatt.PPI.ppi, 'k.')
  - hold on
  - plot(v2att.PPI.ppi,v5att.PPI.ppi, 'r. ');

PPI plotting: draw lines & label

- Draw the regression lines
  - >> lsline
- Label it
  - >> legend('No Attention','Attention')
  - >> xlabel('V2 eigenvariate')
  - >> ylabel('V5 eigenvariate')
  - >> title('Psychophysiologic Interaction')

PPI plotting: graph



THE END