

- Session 1 - Why single-trial EEG analyses?
- Session 2 - Pre-processing, introduction to ICA
 - Example session I: Setting-up your data and running a single-trial regression analysis with the *STA-TB*
- Session 3 - ICA as a tool to increase SNR in EEG data
 - Example session II: COMPASS to select ICs
 - Example session III: EEG regression with independent component activity
- Session 4 - Within-subject to across-subject analyses
 - **Example session IV: Combine data across participants**
- Session 5 - Time-frequency decomposition and single-trial analyses
 - Example session V: Run a TF decomposition and GLM analysis
- End and Discussion

- we have run a regression onto single-trial EEG data and we have for each participant
 - a time-course of b-values for each regressor and electrode
 - a time-course of t-values for each regressor and electrode
 - an overall R^2 time-course
 - for sensor-space data and IC based data
- now we want to combine this across participants and obtain group-level (*2nd level*) statistics
 - most simple model: use mean and *t*-test
 - alternative: construct a 2nd-level model

open Across_Participants_Examples.m

```
%define data and output paths
```

```
pathEEG = 'data/';
```

```
pathBeh = 'Part_Behav/';
```

```
pathAna = 'AnalysisInfo/';
```

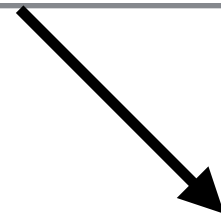
```
pathIn = 'output/for_across/';
```

```
% path to EEG
```

```
% path to behavioural data
```

```
% path to information about analysis steps
```

```
% calculated 'Simple_Error_Model' for 16 participants
```



just the same as we did in the example before
(using sensor space data)

1. Average and t-test

- Most simple way:
 - ▶ average individual participants regression weights and plot these
 - ▶ the weights can be assumed to be normally distributed under H_0 (central limit theorem)
 - ▶ t-test all weights against 0 to determine a p-value at every datapoint and electrode
 - ▶ mask topographies with this p-value (and show significant areas in the regression weight time-course)

```
s1.plotelect      = 'Cz';      % plot electrode
s1.ERP_Im_plot    = 1;        % plot an ERP image
s1.PlotPval       = 1;        % plot a time course for the p-values
s1.UseValues      = 'b';      % use b or t values?
s1.GroupStats     = 0;        % plot group statistics or average within participant values
s1.AddString      = [' ' s1.UseValues]; %we add the value used to the output file
s1.exclude        = [];
```

```
STA_Plot_Regression( [pathIn ModelName '/' ], [pathPic ModelName], s1 )
```


1. Average and t-test

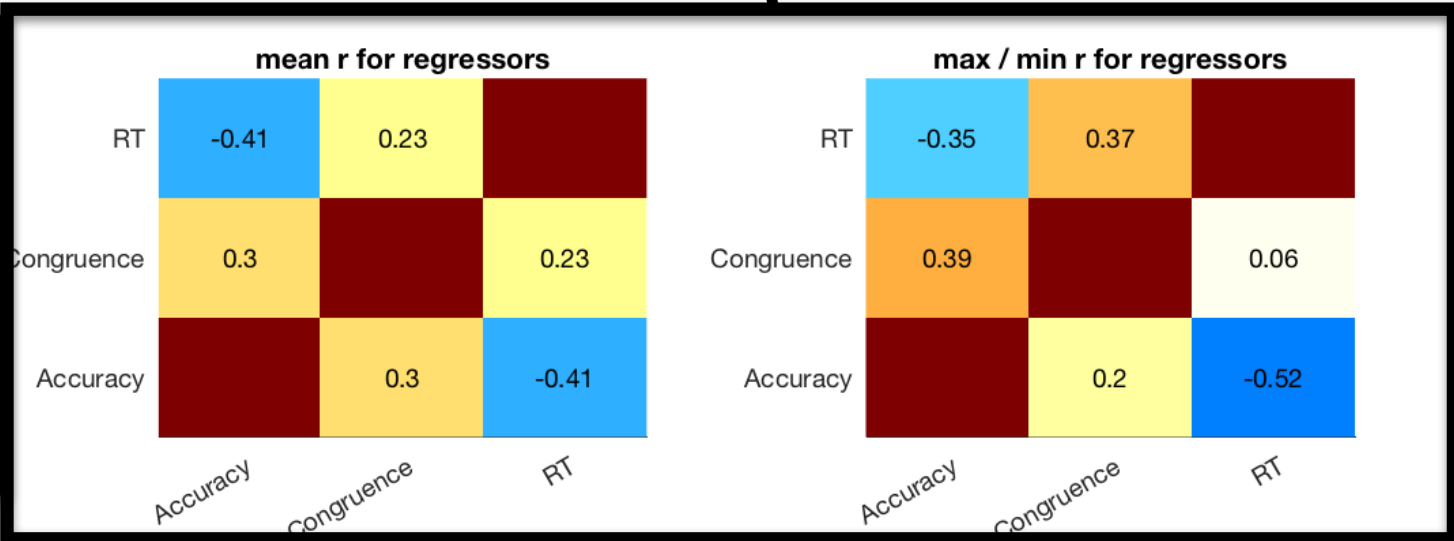
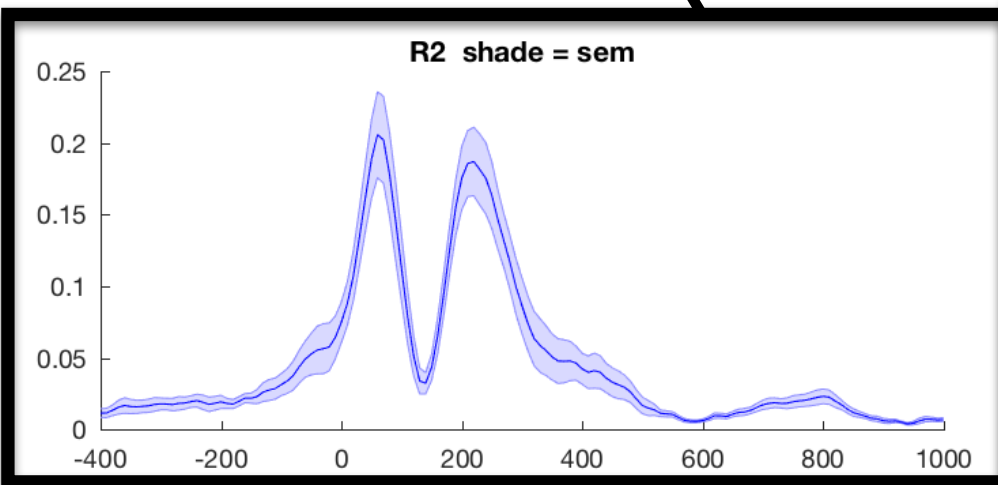
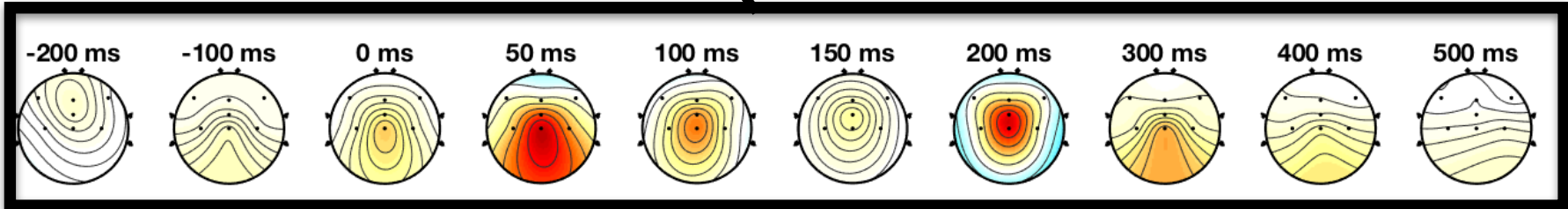
time course of R^2
(shade here = sem,
settings.Confidence
0 = sem (default), 1 = sd,
>0 to <1 = x% confidence intervalls)
Overview at Cz for Simple Error Model b

mean and maximum / minimum
correlation between regressors

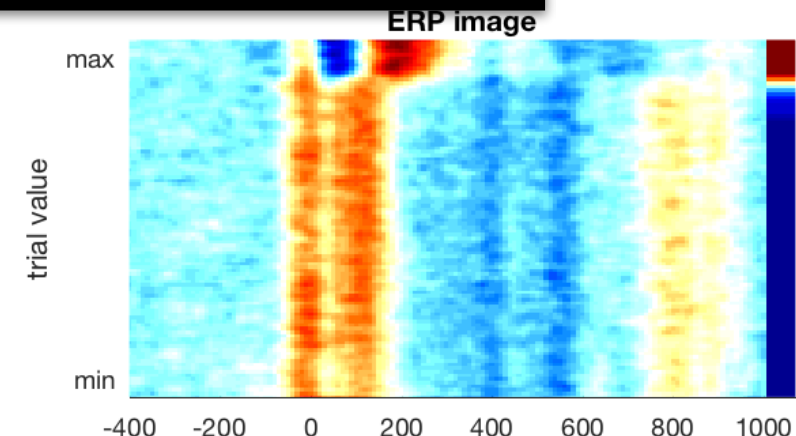
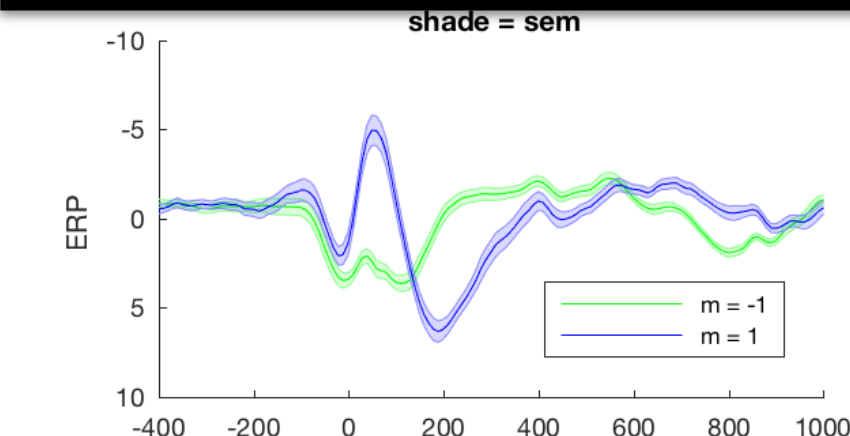
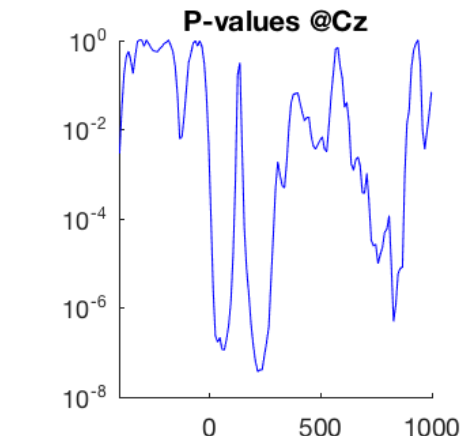
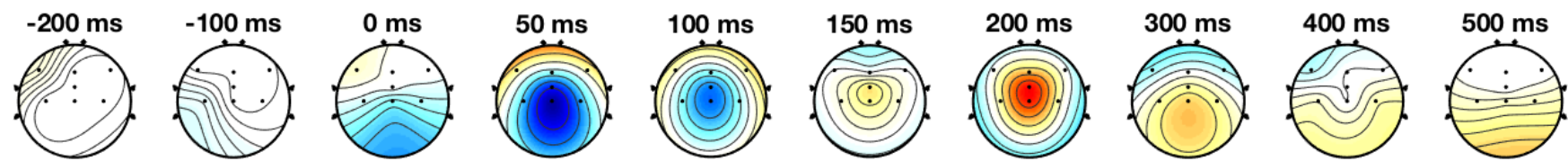
small
overview

topographies of R^2 plot
(how much variance can
we explain on average?)

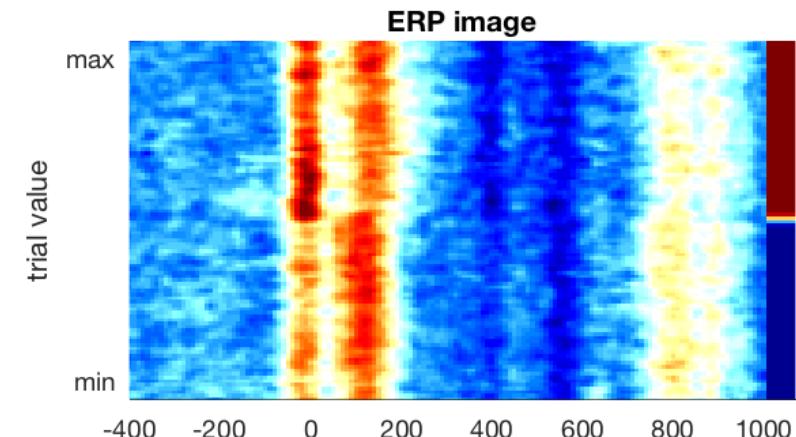
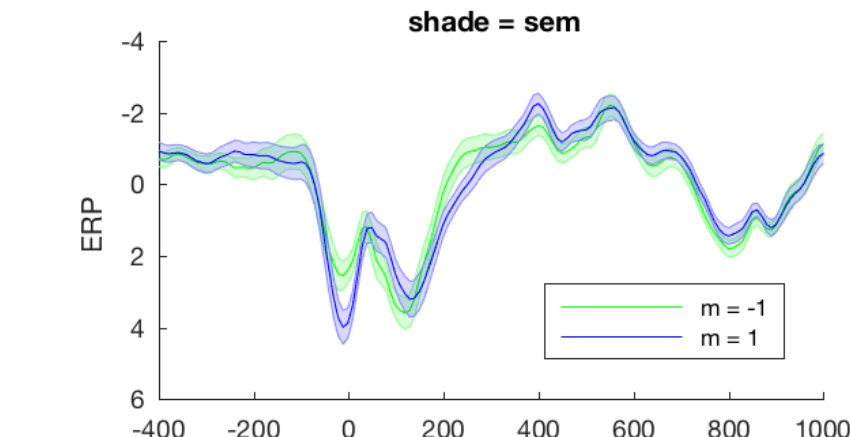
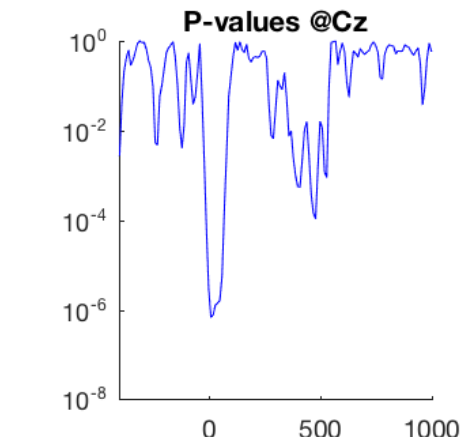
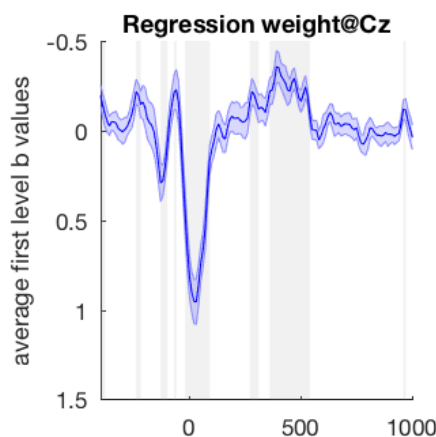
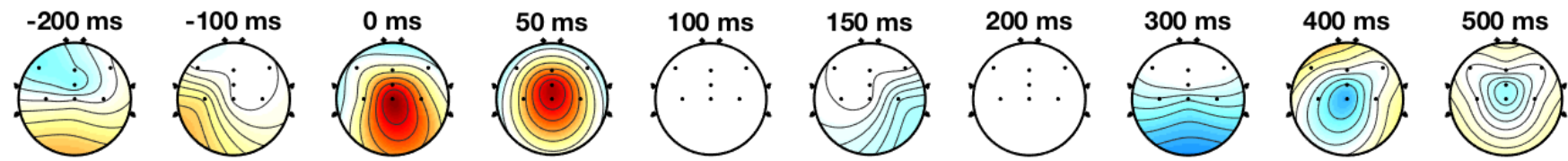
Overall R^2
n subjects: 16
n Regressors 3
Min 0.004
Max 0.206 at 60 ms



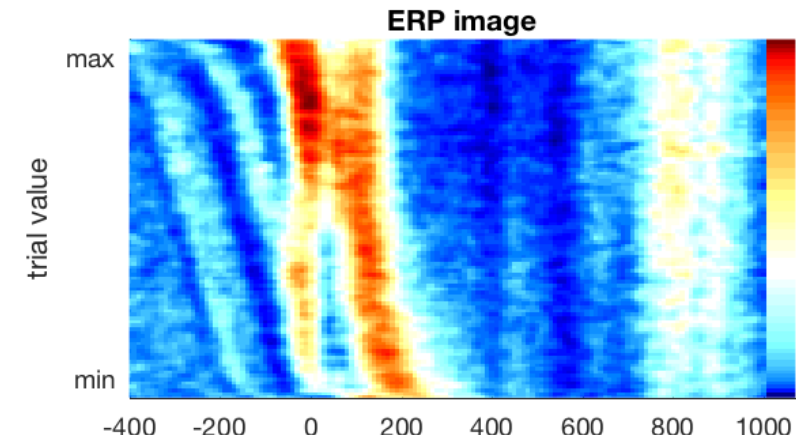
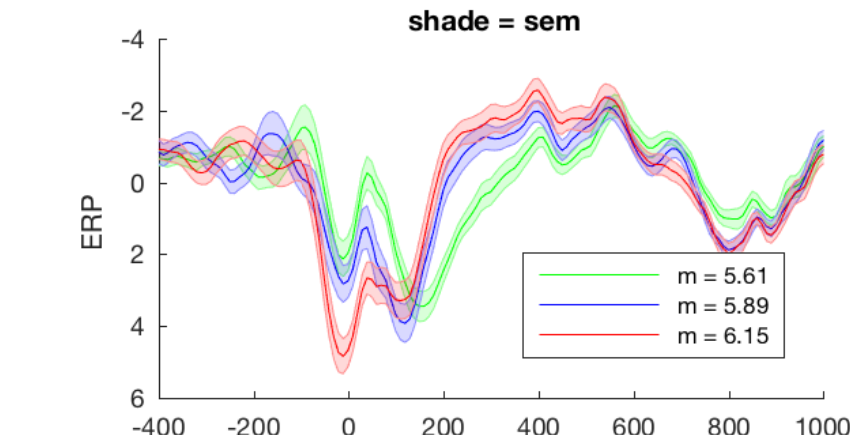
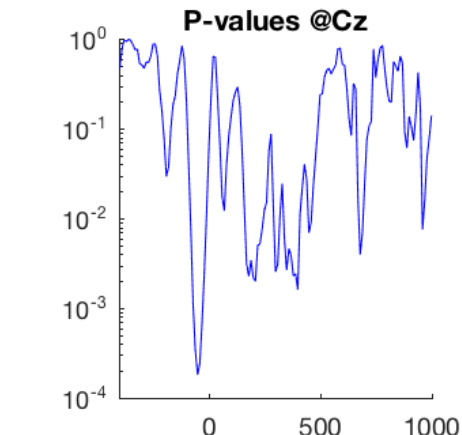
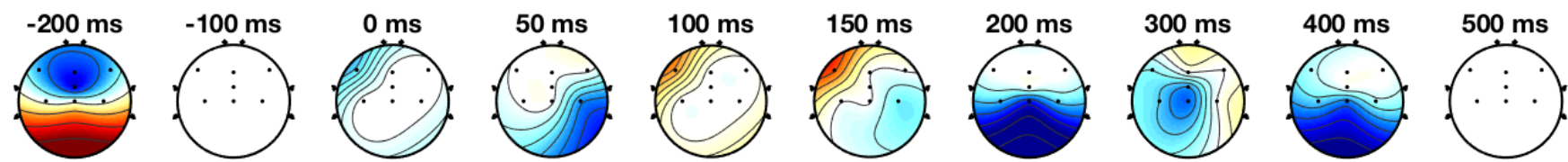
Regressor: Accuracy
-1 = cor
1 = err
Maplimits -4.32 4.32
Maplimits -4.32 4.32
Crit p = 0.05
Max 3.14 at 210 ms
Min -4.57 at 60 ms
p max = 6.23×10^{-8}
p min = 1.16×10^{-7}



Regressor: Congruence
-1 = con
1 = inc
Maplimits -0.82 0.82
Maplimits -0.82 0.82
Crit p = 0.05
Max 0.96 at 30 ms
Min -0.36 at 390 ms
p max = 1.27×10^{-6}
p min = 0.00098313



Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -2.4 2.4
Maplimits -2.4 2.4
Crit p = 0.05
Max 4.67 at -40 ms
Min -2.05 at 70 ms
p max = 0.00023971
p min = 0.012231



1. Average and t-test

masked scalp topographies
(white > critical p-value)

exact 2nd
level p-values

averaged ERP images
(extra- and
interpolated
to dimensions set in
first-level
analysis)

average b-values
per participant + sem
(s.Confidence)

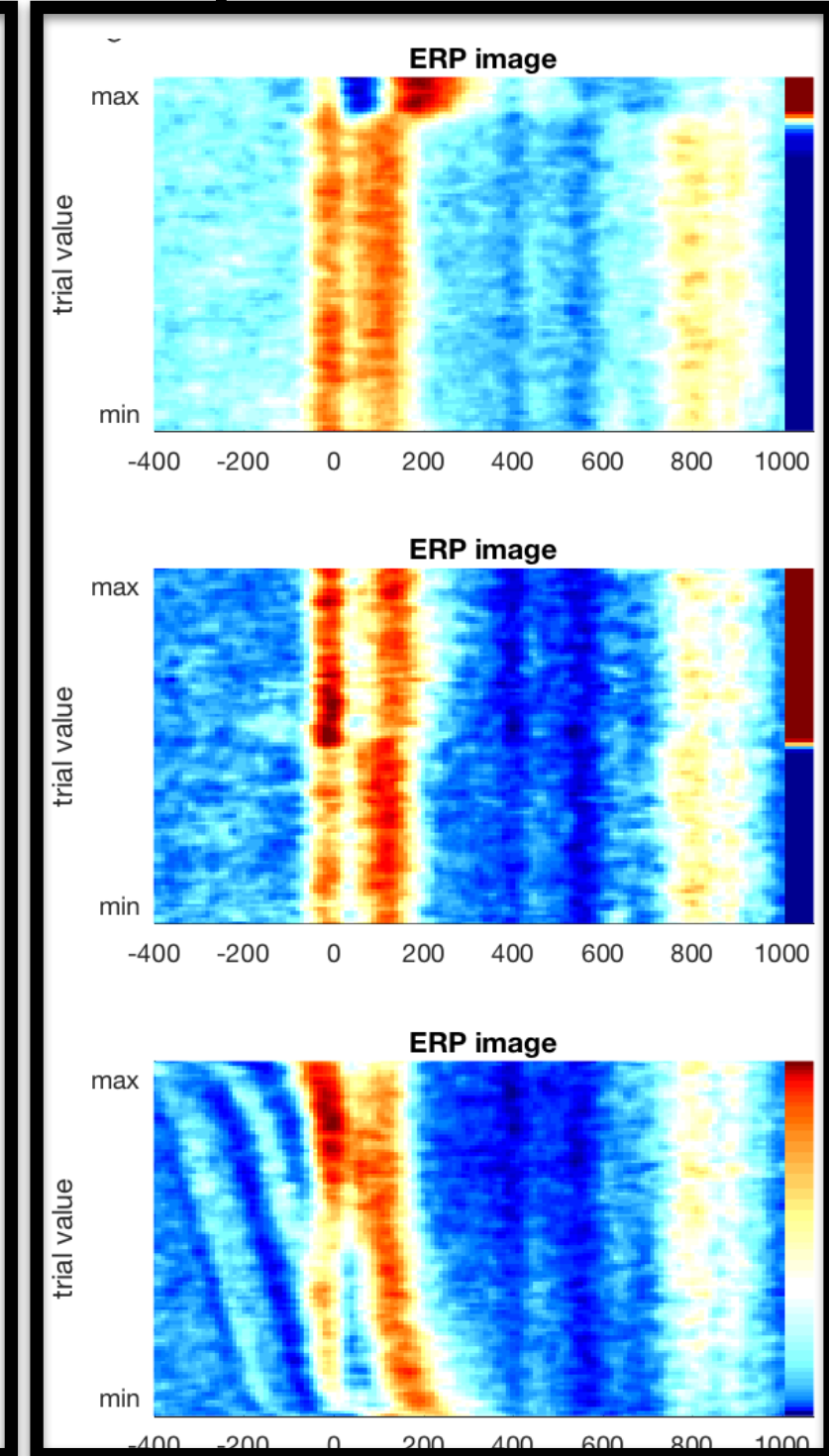
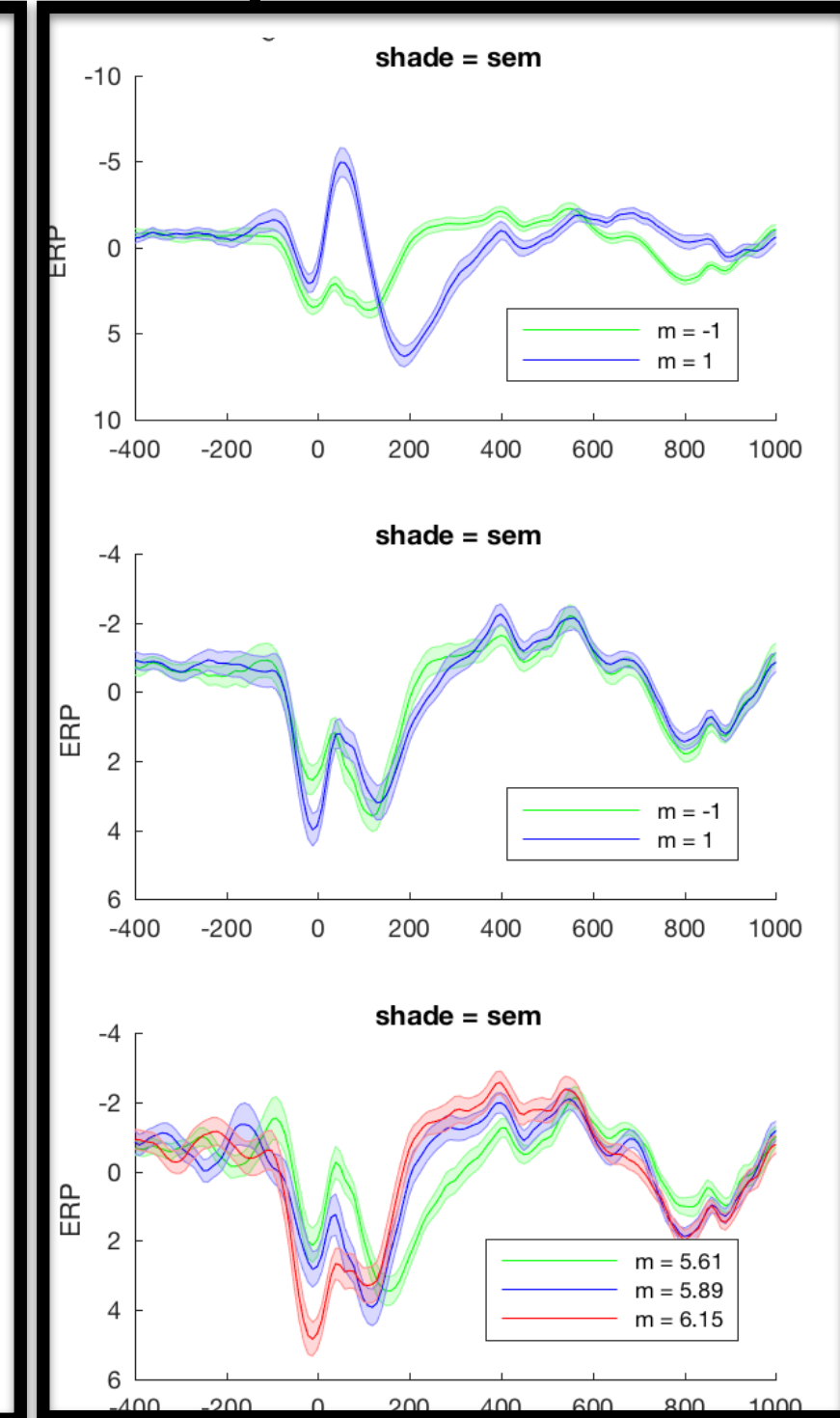
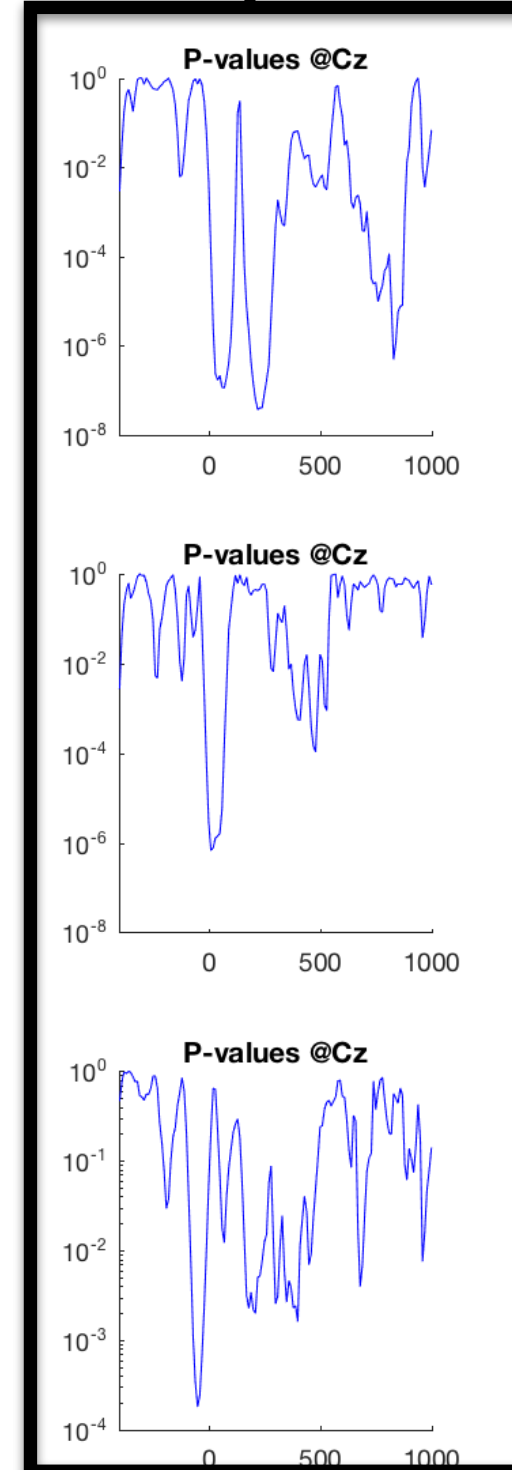
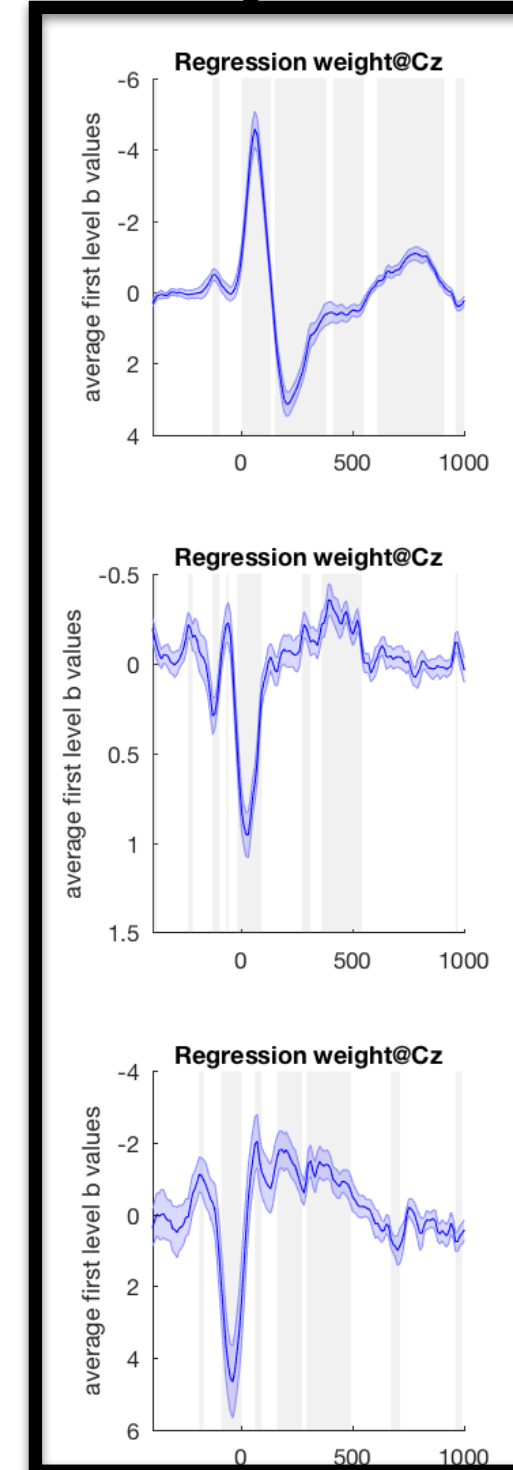
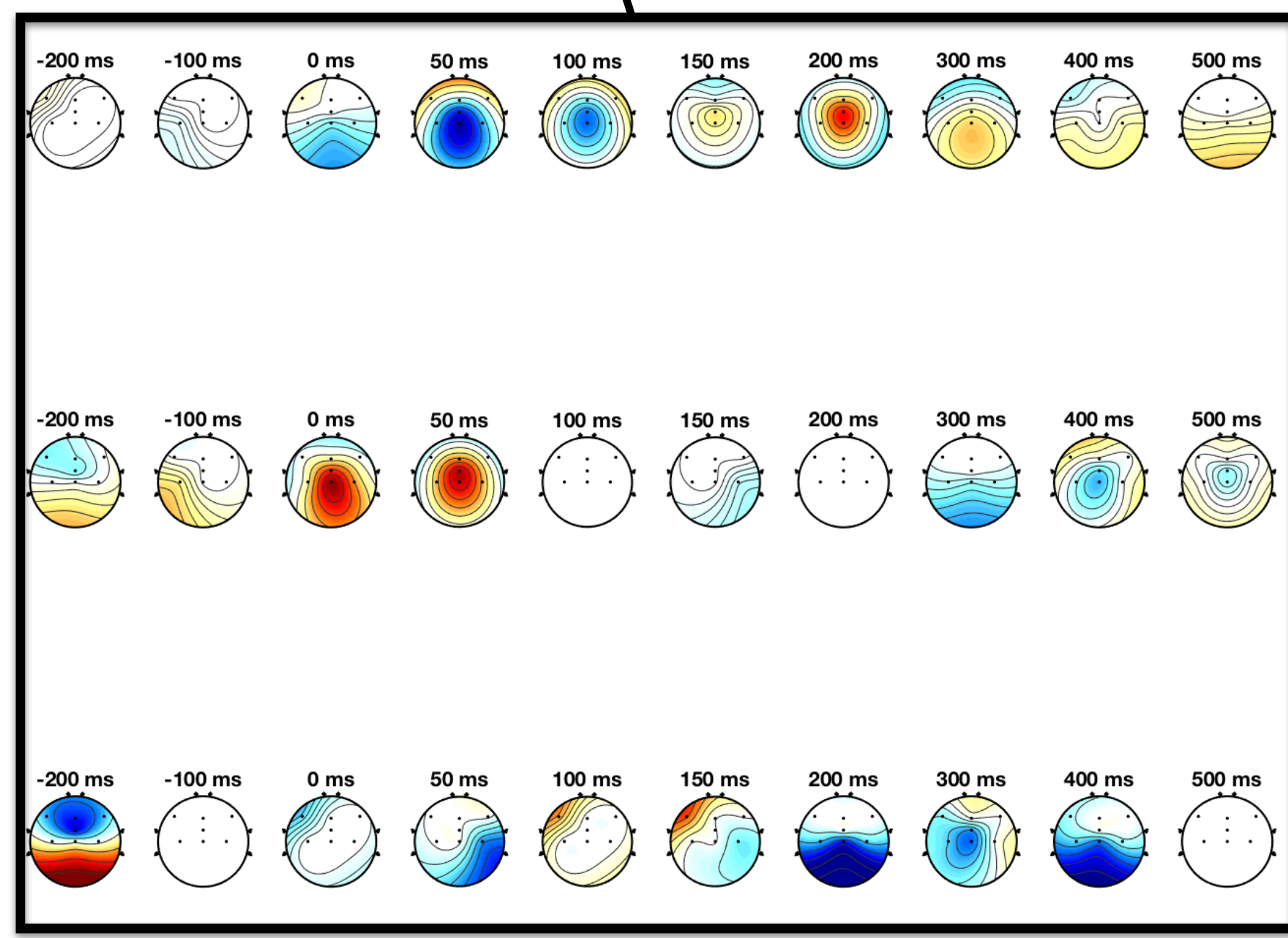
grand-average ERP
for comparison
and validation

regressors used,
p value for masking,
max / min statistics

Regressor: Accuracy
-1 = cor
1 = err
Maplimits -4.32 4.32
Maplimits -4.32 4.32
Crit p = 0.05
Max 3.14 at 210 ms
Min -4.57 at 60 ms
p max = 6.23×10^{-8}
p min = 1.16×10^{-7}

Regressor: Congruence
-1 = con
1 = inc
Maplimits -0.82 0.82
Maplimits -0.82 0.82
Crit p = 0.05
Max 0.96 at 30 ms
Min -0.36 at 390 ms
p max = 1.27×10^{-6}
p min = 0.00098313

Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -2.4 2.4
Maplimits -2.4 2.4
Crit p = 0.05
Max 4.67 at -40 ms
Min -2.05 at 70 ms
p max = 0.00023971
p min = 0.012231



1.1 Example with ICs

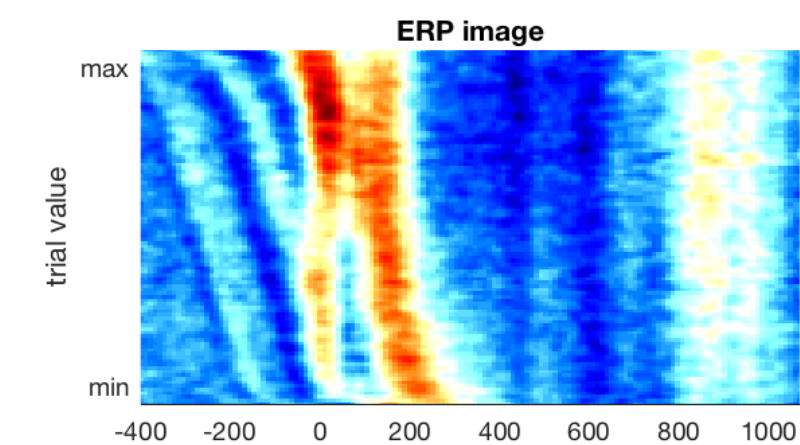
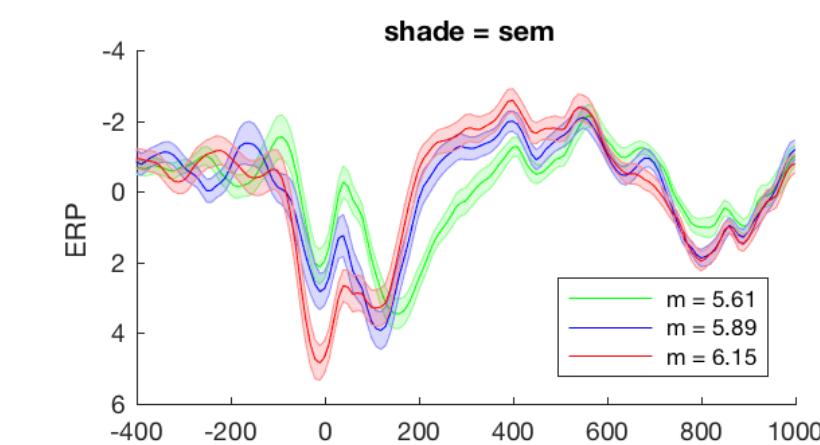
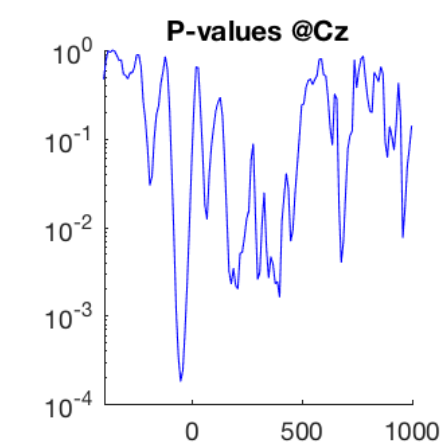
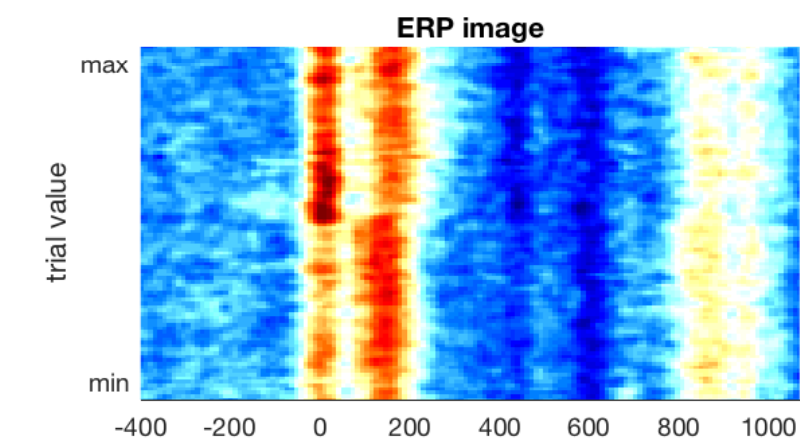
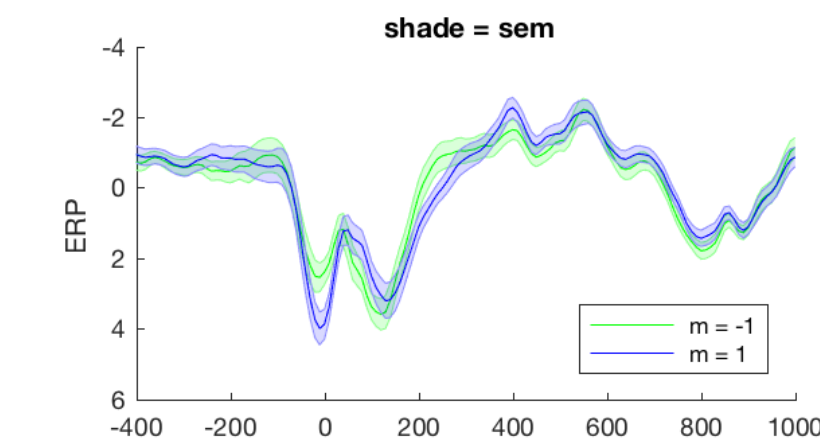
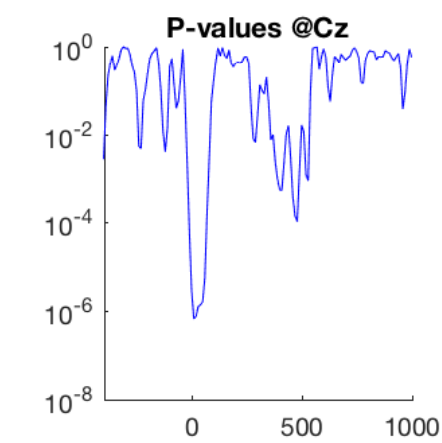
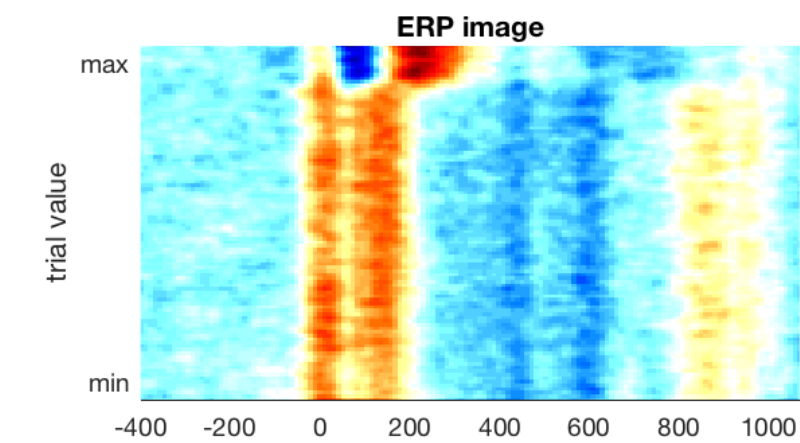
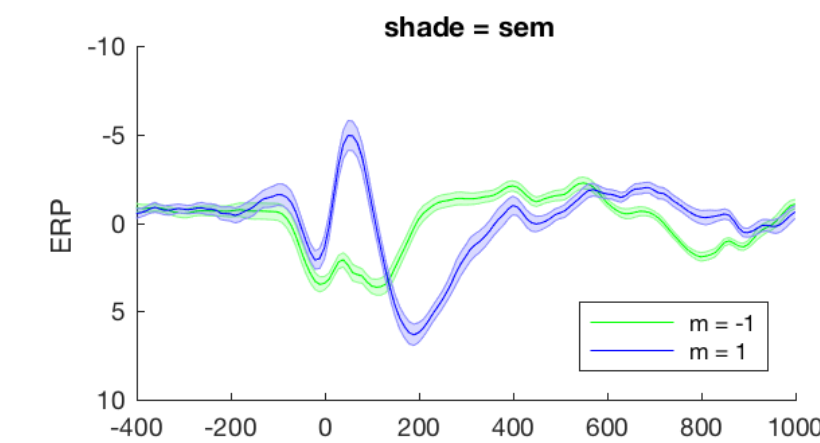
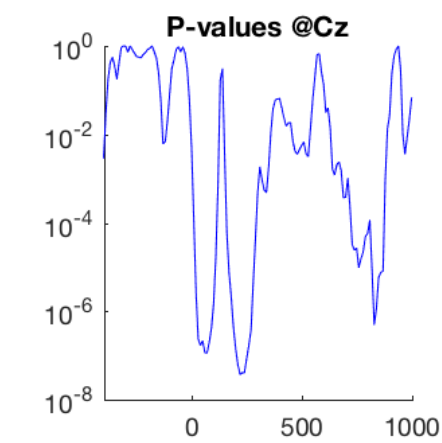
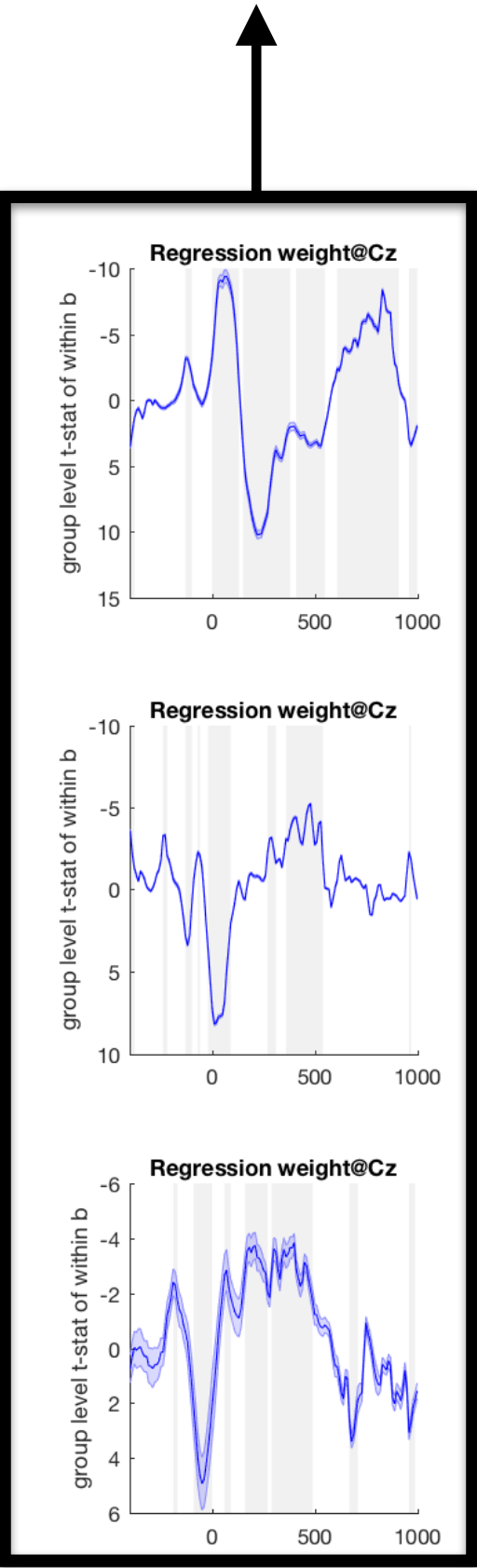
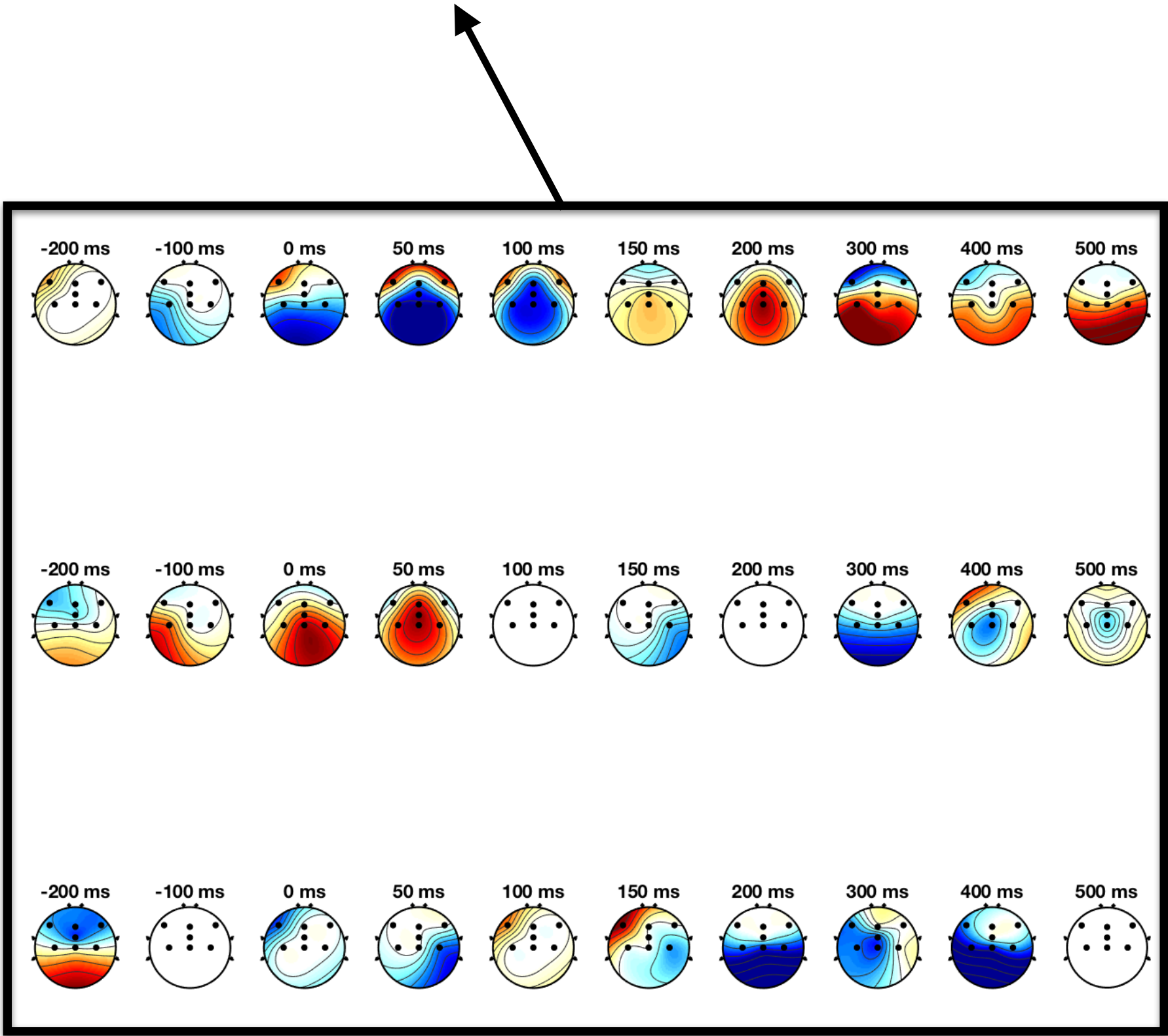
- Group model in ICs
- IC based post-error slowing model

2. Group stats

s1.GroupStats = 1; % plot group statistics or average within participant values

scalp topographies of 2nd level t-maps

second level t-values (from within-subject b-values)



2. Group stats

s1.GroupStats = 0;

s1.GroupStats = 1;

Regressor: Accuracy
-1 = cor
1 = err
Maplimits -4.32 4.32
Maplimits -4.32 4.32
Crit p = 0.05
Max 3.14 at 210 ms
Min -4.57 at 60 ms
p max = 6.23×10^{-8}
p min = 1.16×10^{-7}

Regressor: Accuracy
-1 = cor
1 = err
Maplimits -9.22 9.22
Maplimits -9.22 9.22
Crit p = 0.05
Max 10.23 at 220 ms
Min -9.39 at 70 ms
p max = 3.70×10^{-8}
p min = 1.13×10^{-7}

because of different peaks
(maximum average b-value
does not have to be the
most significant point
because of associated
variance!)

slightly
different

Regressor: Congruence
-1 = con
1 = inc
Maplimits -0.82 0.82
Maplimits -0.82 0.82
Crit p = 0.05
Max 0.96 at 30 ms
Min -0.36 at 390 ms
p max = 1.27×10^{-6}
p min = 0.00098313

Regressor: Congruence
-1 = con
1 = inc
Maplimits -7.93 7.93
Maplimits -7.93 7.93
Crit p = 0.05
Max 8.16 at 10 ms
Min -5.21 at 480 ms
p max = 6.72×10^{-7}
p min = 0.00010622

Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -2.4 2.4
Maplimits -2.4 2.4
Crit p = 0.05
Max 4.67 at -40 ms
Min -2.05 at 70 ms
p max = 0.00023971
p min = 0.012231

Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -4.96 4.96
Maplimits -4.96 4.96
Crit p = 0.05
Max 4.94 at -50 ms
Min -3.84 at 400 ms
p max = 0.00017955
p min = 0.0016094

3. FWER correction: Bonferroni

- So far, we just defined an arbitrary threshold for significance ($p < 0.05$)

```
s1.MaskPval = 'bonf3';
```

Set to '**bonf1**' to correct each regressor for every point in time using Bonferroni correction.

Set to '**bonf2**' to correct each regressor for all points in all electrodes (very conservative).

Set to '**bonf3**' to correct each regressor for every electrode and the total number of plotted regressors (probably too conservative).

are we really
testing 2961
hypotheses?

```
*****Starting Plot Regression Script...*****
Found 16 files in folder output/for across/Simple Error Model/.
Plots masked for 2961 multiple comparisons using Bonferroni correction.
Regresison model Simple Error Model includes 7 electrodes and -400 until 1000ms.
Number of regressors is 3 and time window for plotting -400 to 1000 ms.
In the model 3 out of 3 regressors have been returned.
3 regressors will be plotted.
These are:
    Reg no 1: Accuracy
    Reg no 2: Congruence
    Reg no 3: RT
```

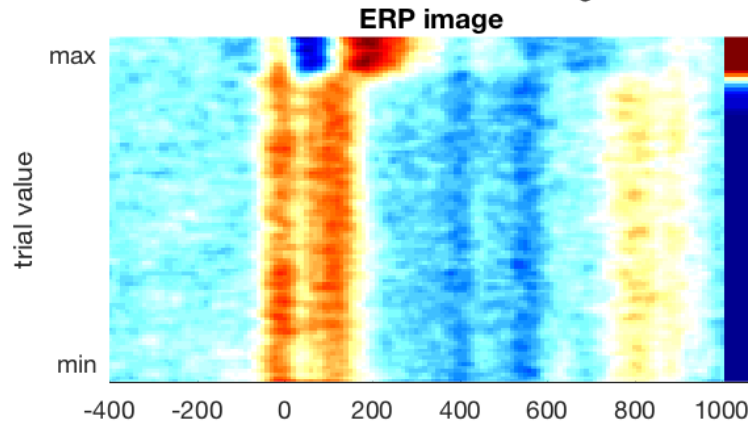
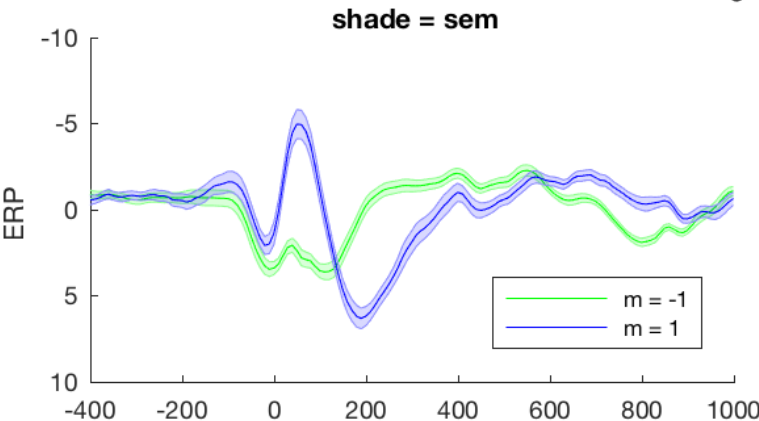
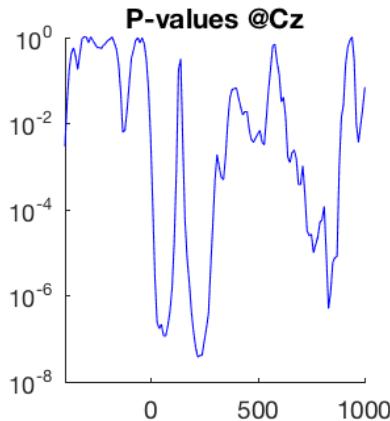
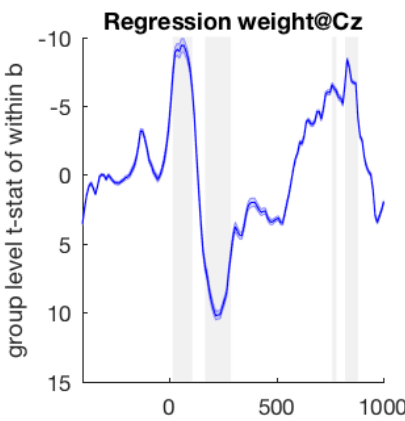
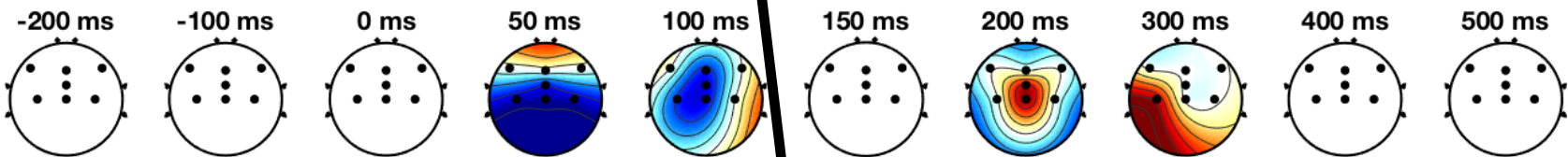
Bonferroni result

Overview at Cz for Simple Error Model b group t bonferroni over everything

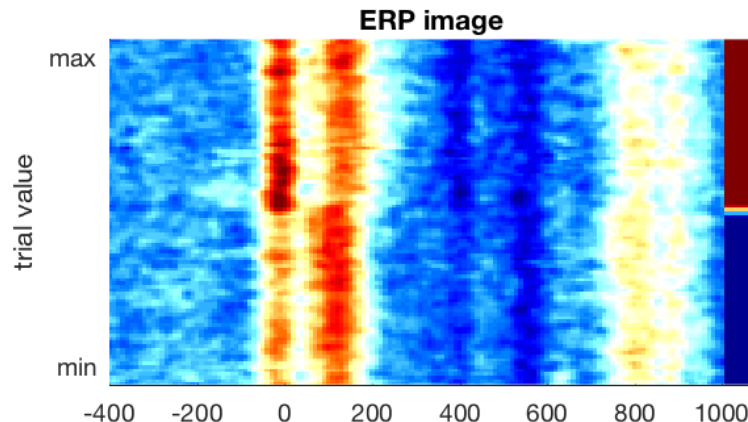
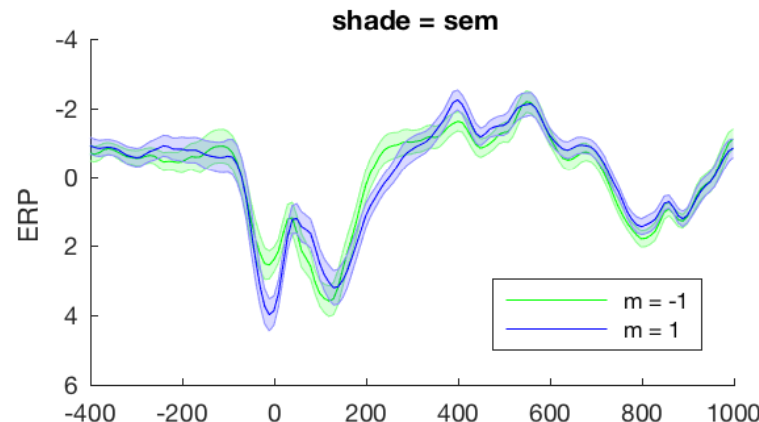
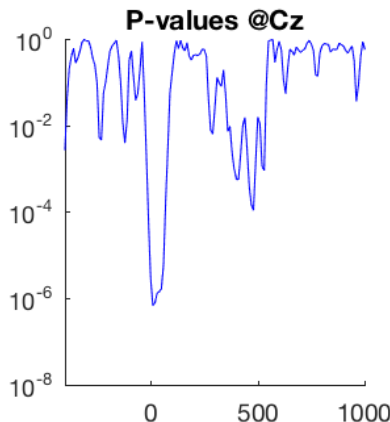
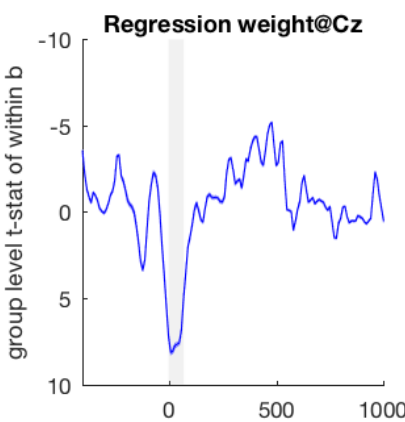
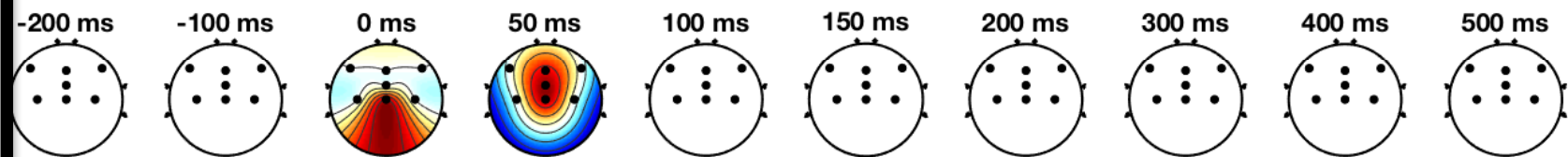
effect would be undetected

mean r for regressors			max / min r for regressors		
RT	-0.41	0.23	RT	-0.35	0.37
Congruence	0.3	0.23	Congruence	0.39	0.06
Accuracy	0.3	-0.41	Accuracy	0.2	-0.52
Accuracy		Congruence	Accuracy		Congruence
		RT			RT

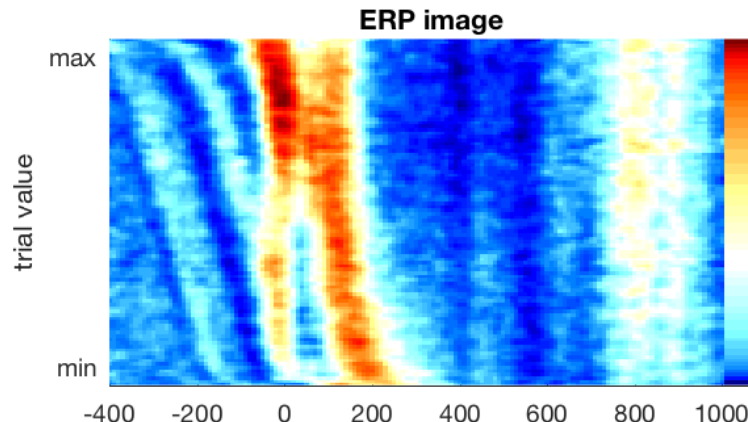
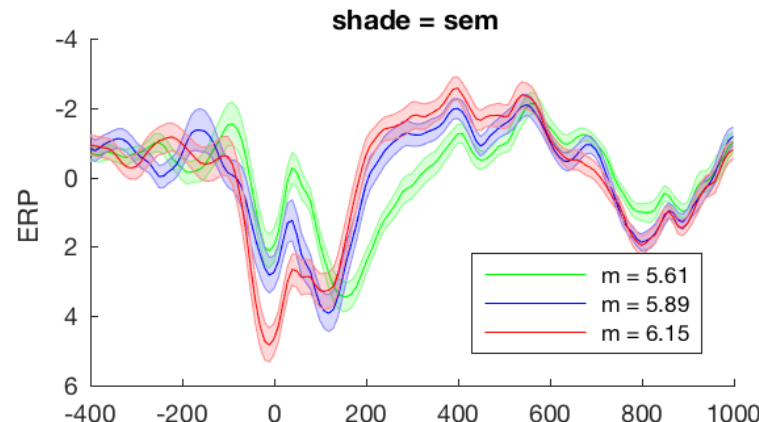
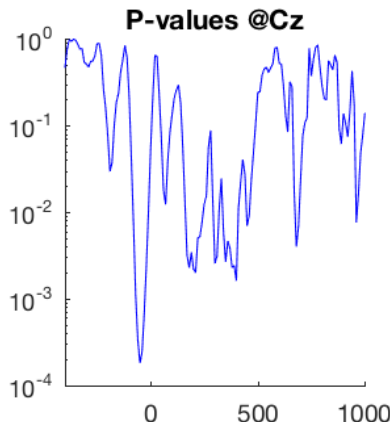
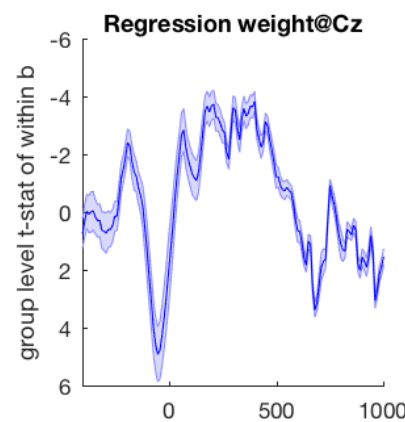
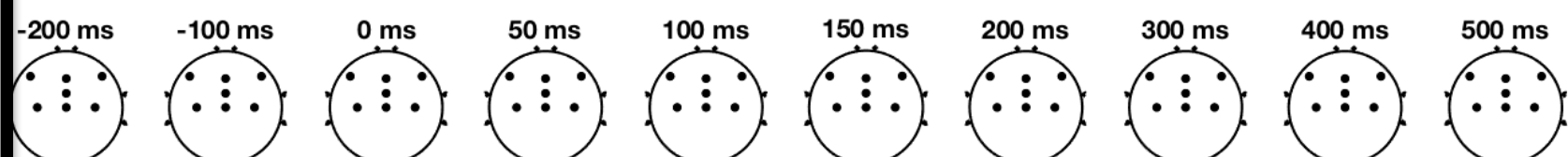
Regressor: Accuracy
-1 = cor
1 = err
Maplimits -9.22 9.22
Maplimits -9.22 9.22
Crit p = 1.68x10⁻⁵
Max 10.23 at 220 ms
Min -9.39 at 70 ms
p max = 3.70x10⁻⁸
p min = 1.13x10⁻⁷



Regressor: Congruence
-1 = con
1 = inc
Maplimits -7.93 7.93
Maplimits -7.93 7.93
Crit p = 1.68x10⁻⁵
Max 8.16 at 10 ms
Min -5.21 at 480 ms
p max = 6.72x10⁻⁷
p min = 0.00010622



Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -4.96 4.96
Maplimits -4.96 4.96
Crit p = 1.68x10⁻⁵
Max 4.94 at -50 ms
Min -3.84 at 400 ms
p max = 0.00017955
p min = 0.0016094



3. FWER correction: Bonferroni

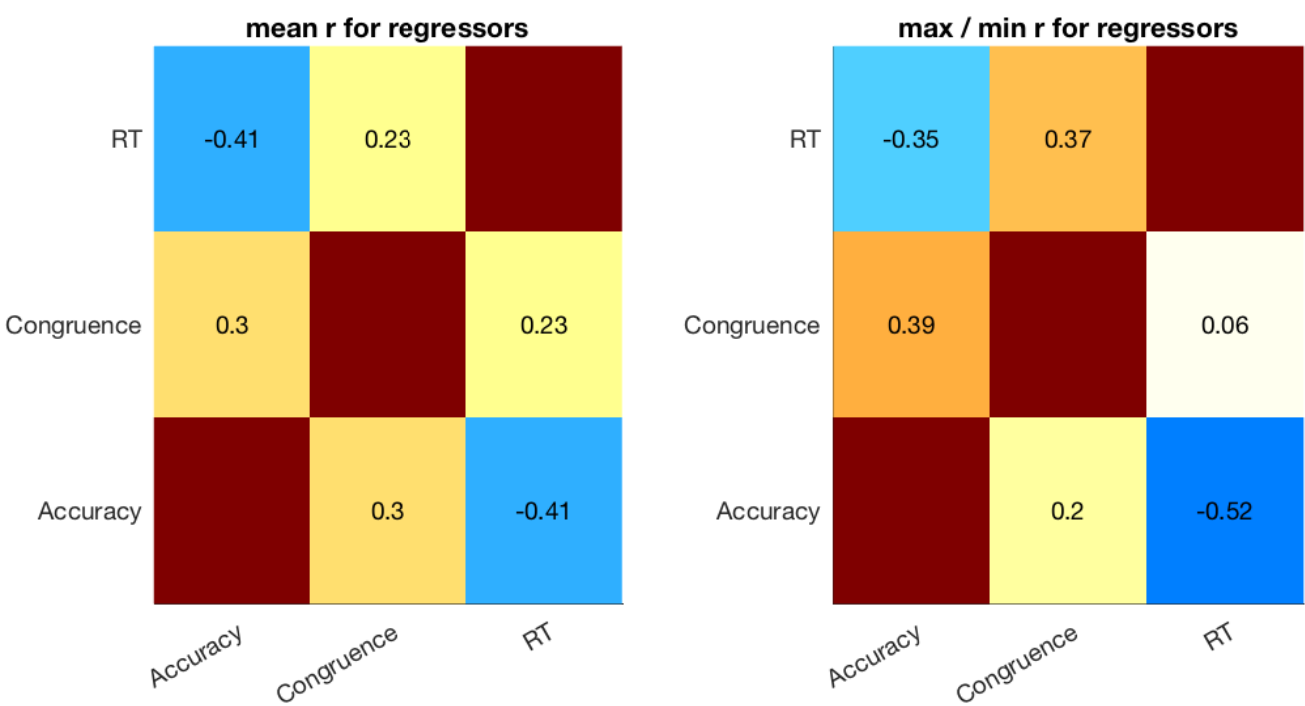
- Alternatively (also when many regressors have been used in the model!), we remove regressors from the analysis that are not of interest to us:

```
s1.MaskPval      = 'bonf3';    %Bonferroni correction over every data point, electrode, and regressors
s1.PlotReg       = [1];       %Plots only the regressors selected here
s1.AddString     = [' ' s1.UseValues ' group t bonferroni over everything']; %we add the value used to the output file
```

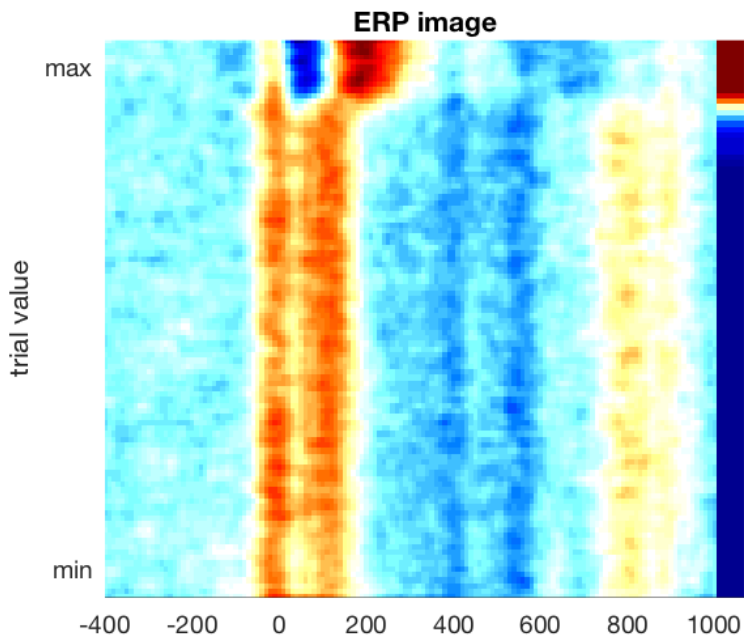
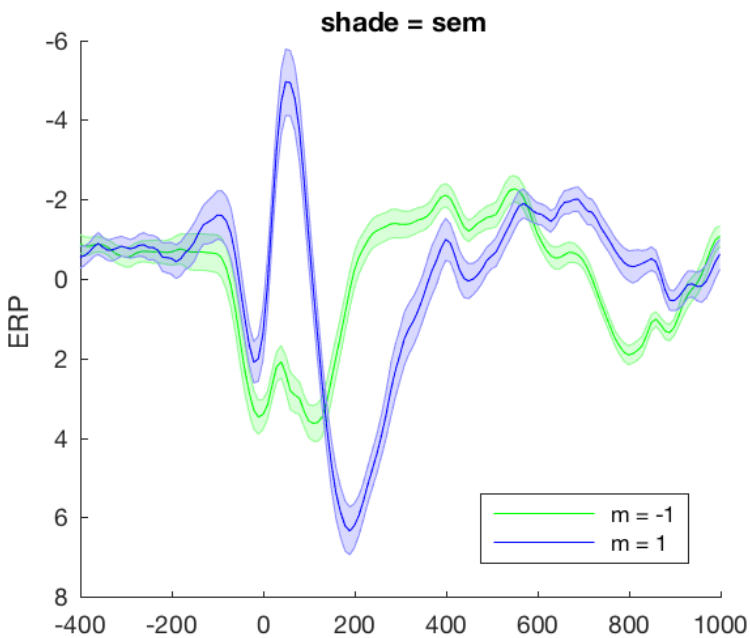
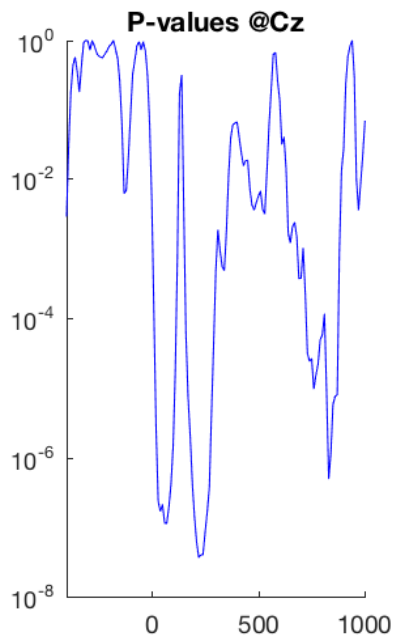
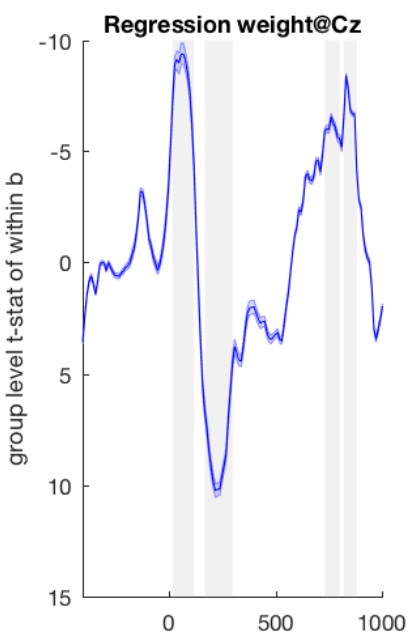
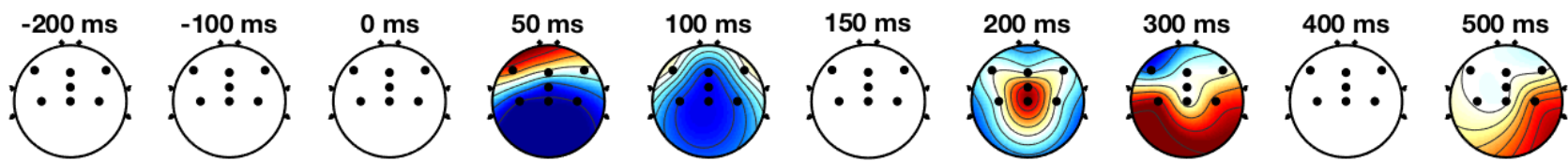
Note: If you remove regressors (and electrodes!) from plotting, all FWER corrections are applied to the remaining data alone. This allows to explore data, and maintain appropriate flexibility to incorporate *a priori* hypotheses

Example: you expect an effect at frontal electrodes, but it is still nice to have a topography plot of the whole scalp!

Overview at Cz for Simple Error Model b group t bonferroni for accuracy

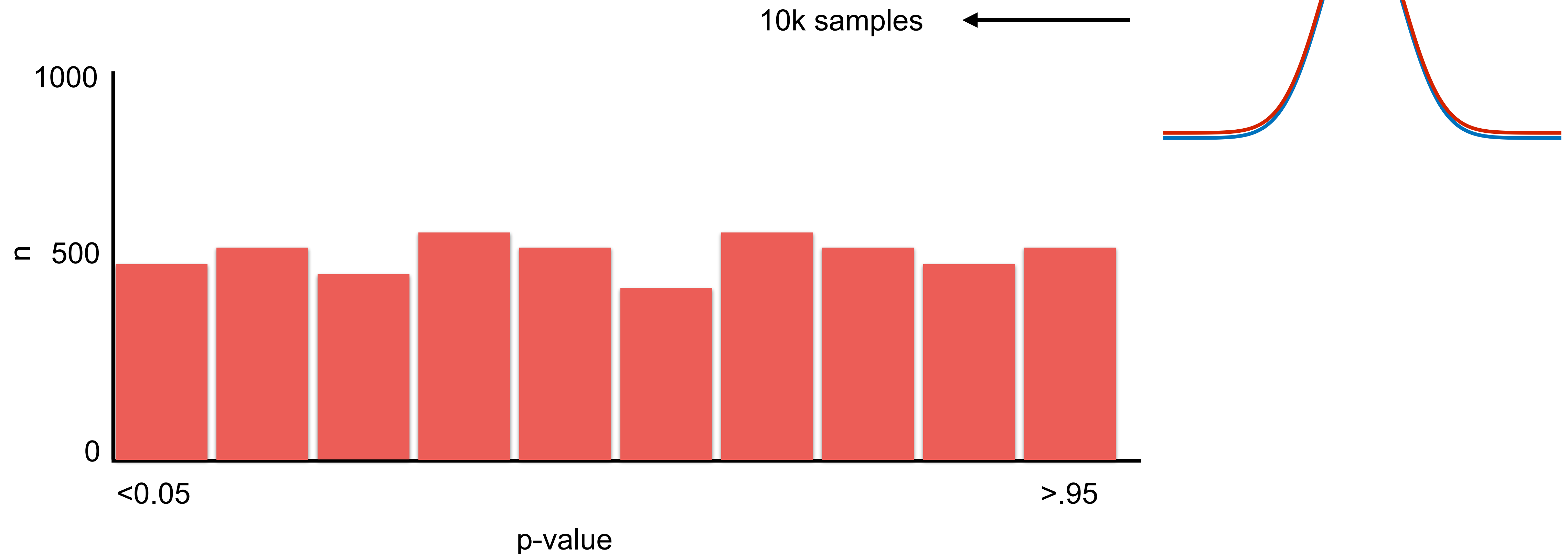


Regressor: Accuracy
-1 = cor
1 = err
Maplimits -9.22 9.22
Maplimits -9.22 9.22
Crit p = 5.06x10⁻⁵
Max 10.23 at 220 ms
Min -9.39 at 70 ms
p max = 3.70x10⁻⁸
p min = 1.13x10⁻⁷

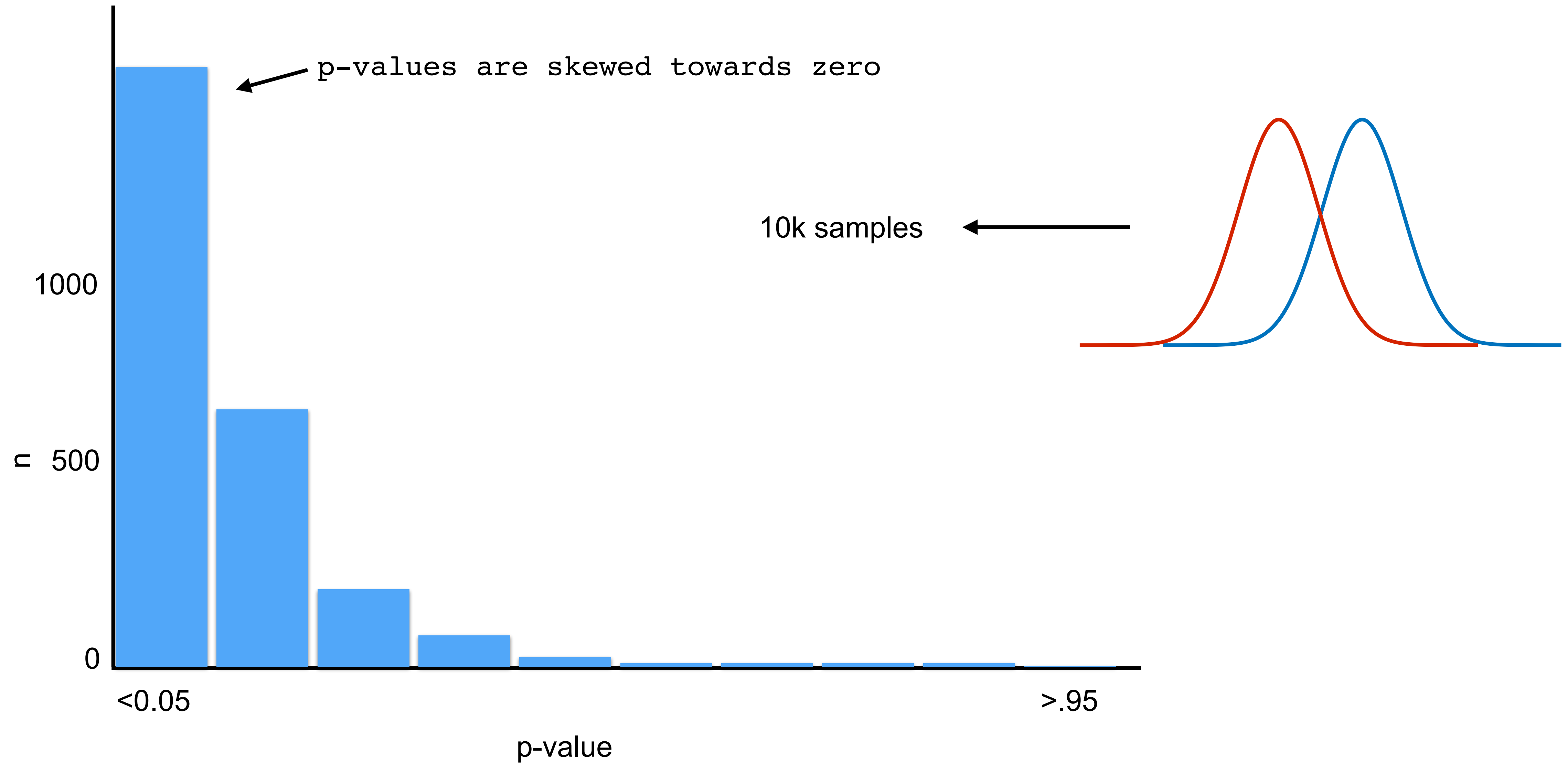


4. FDR

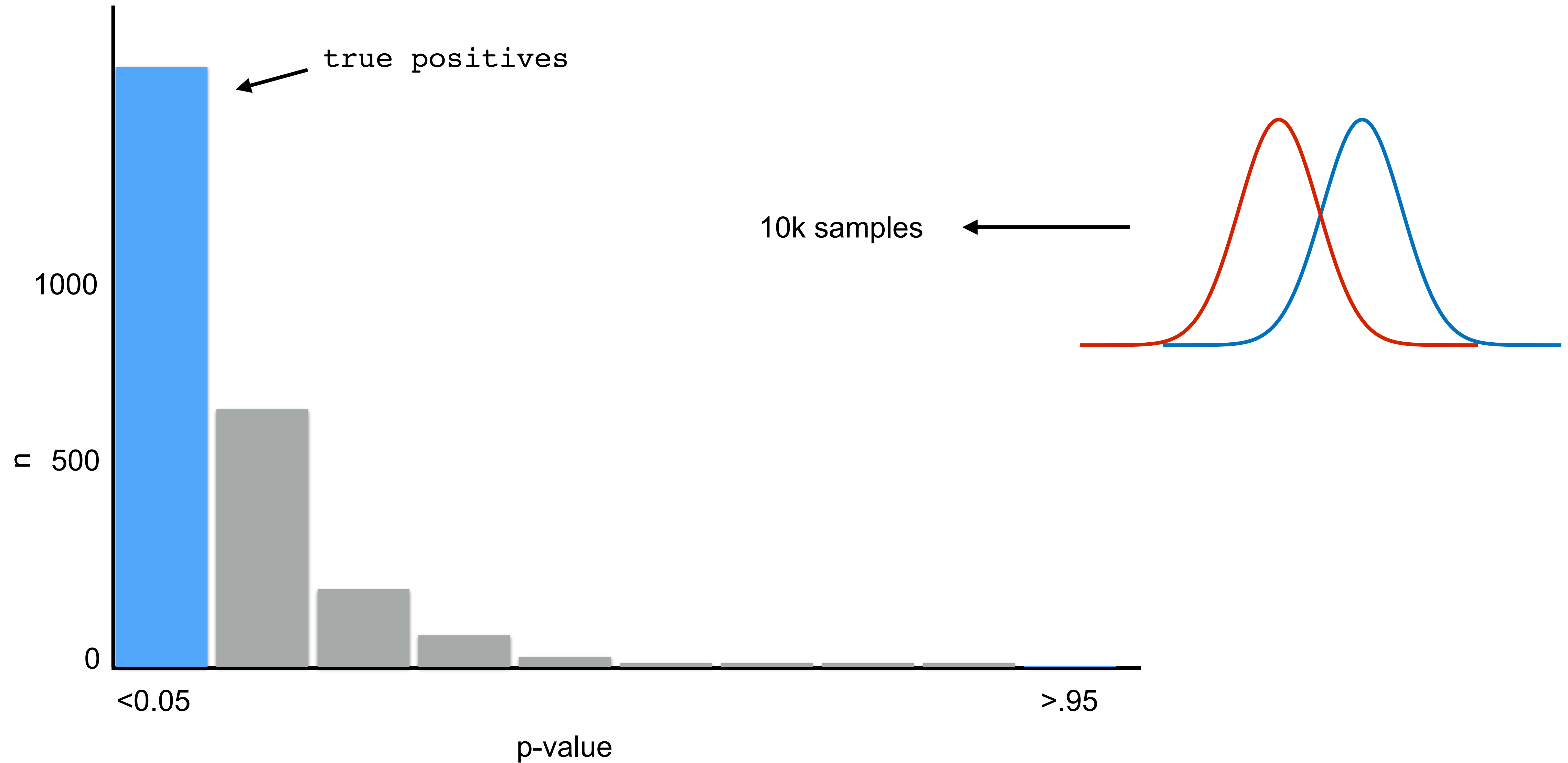
- Does not control the actual FWER, but the *fraction of false positives among those tests that are reported as significant*.



4. FDR

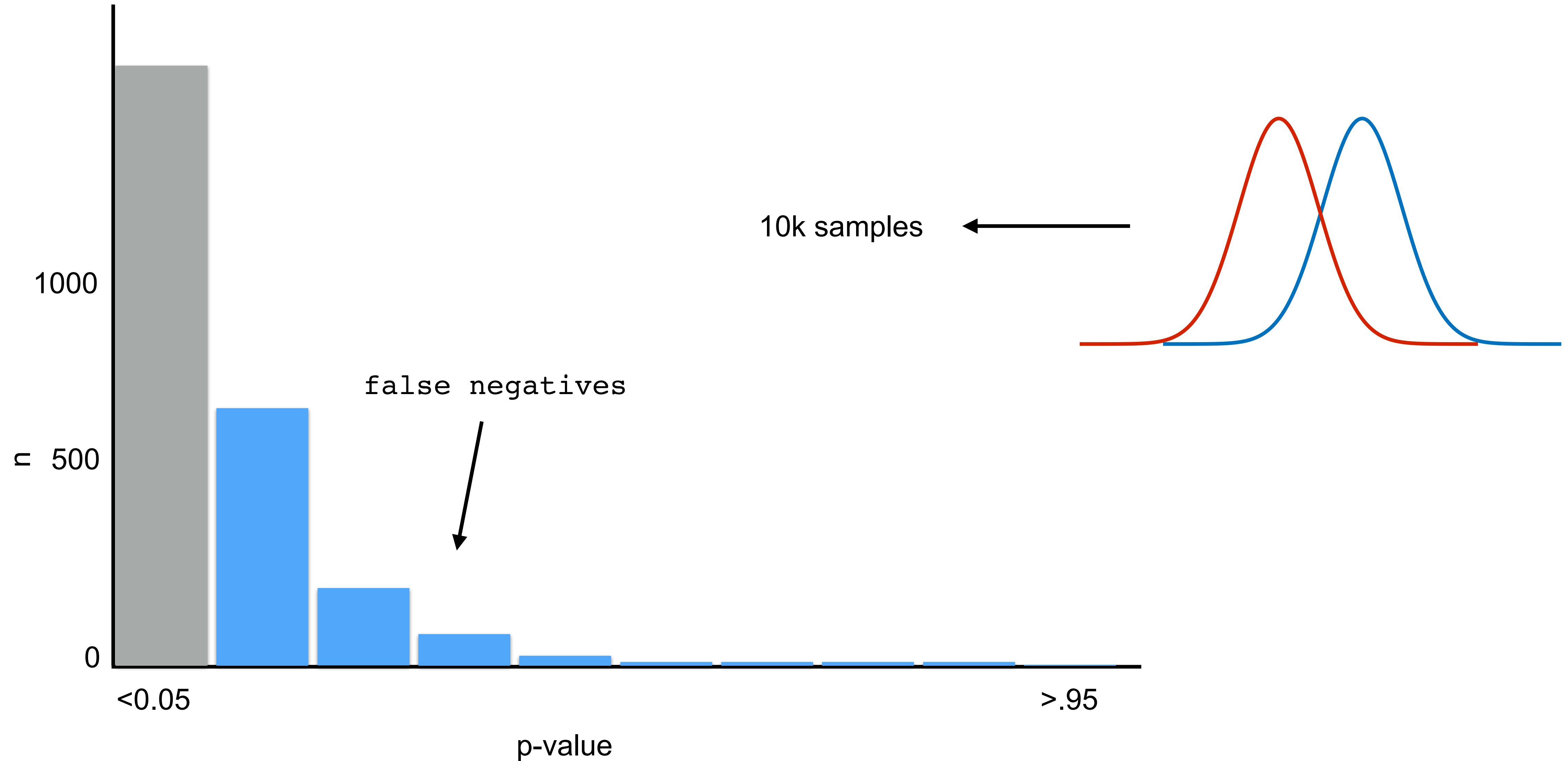


4. FDR



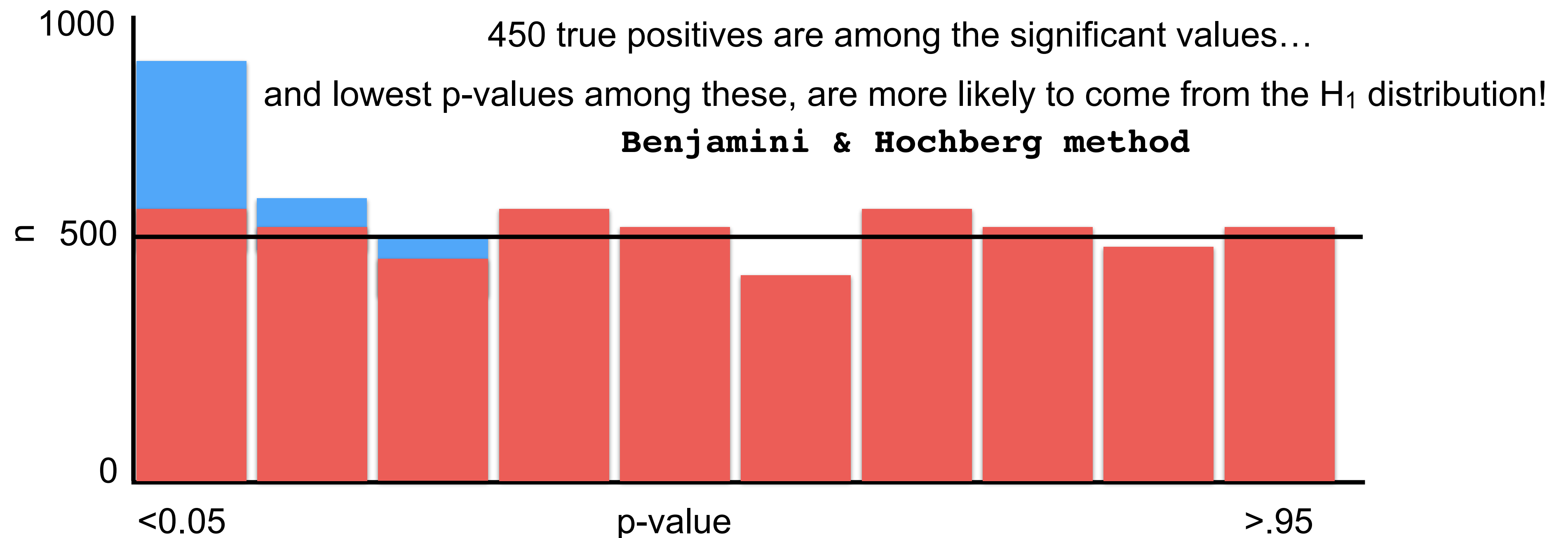
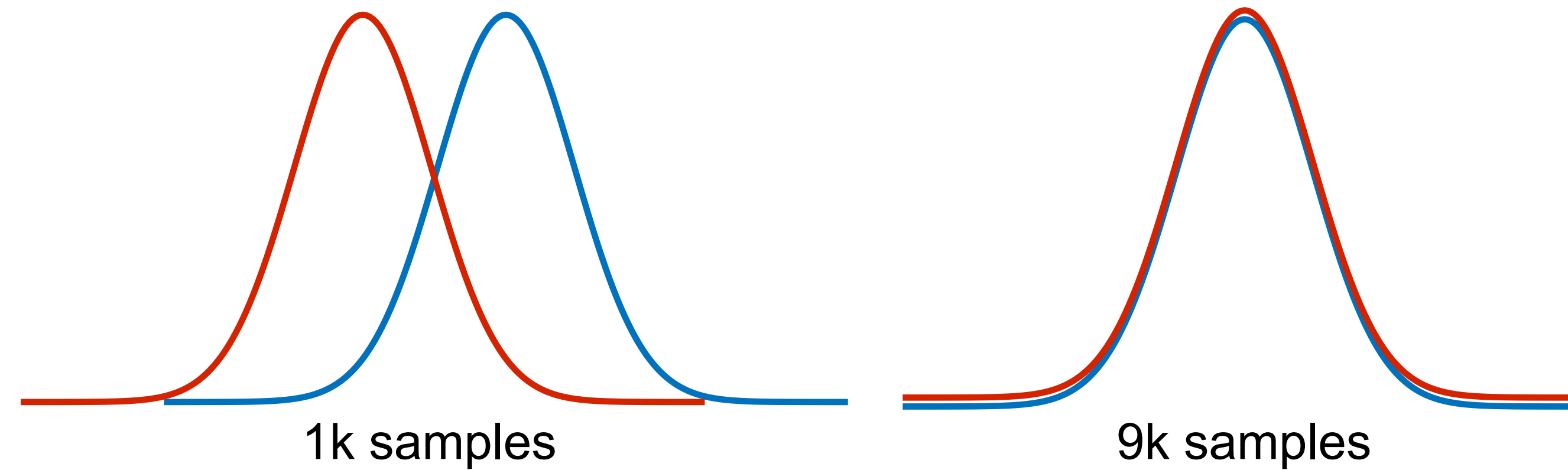
4. FDR

in EEG, some time points / electrodes may reflect a true effect,
but almost certainly, others do not!

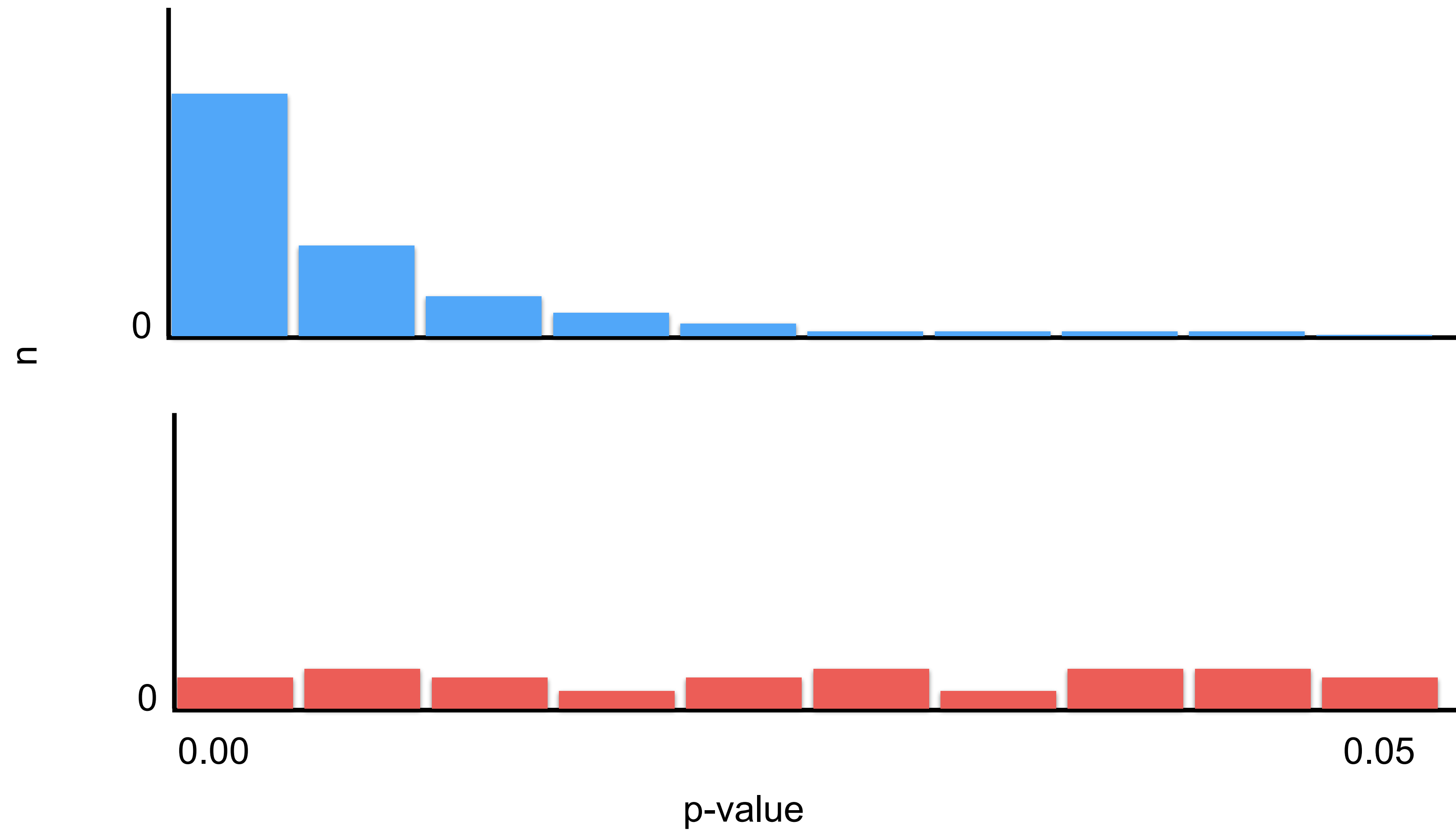


4. FDR

in EEG, some time points / electrodes may reflect a true effect,
but almost certainly, others do not!

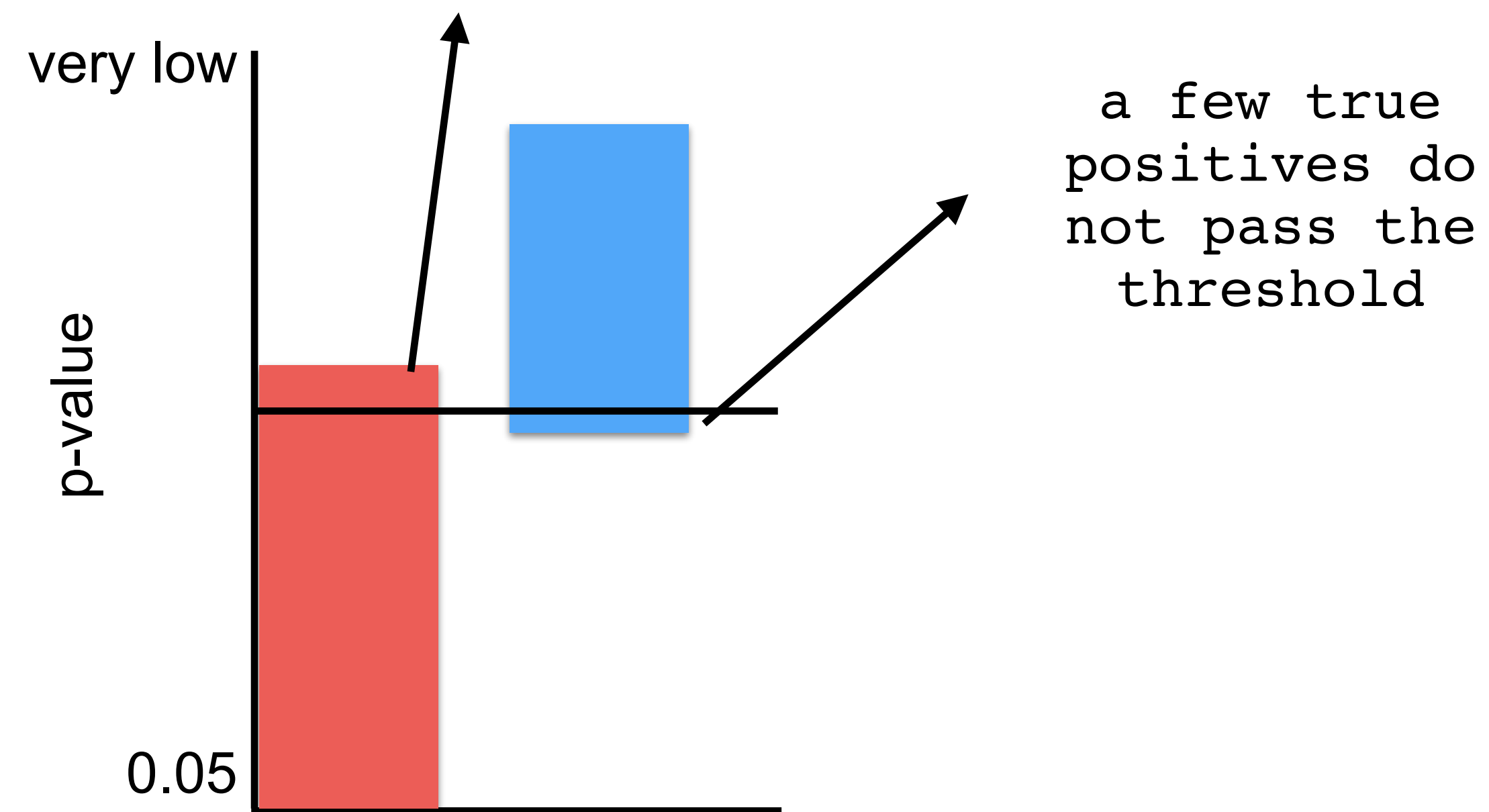


4. FDR



4. FDR

only 5% of the positive values,
are false positives



4. FDR

Rank	p	threshold at q = 0.05	Reject H ₀ ?
1	0.00005	0.005	1
2	0.0006	0.01	1
3	0.02	0.015	0
4	0.2	0.02	0
5	0.34	0.025	0
6	0.45	0.03	0
7	0.8	0.035	0
8	0.85	0.04	0
9	0.9	0.045	0
10	0.99	0.05	0

q / m (sample size) x rank
q = false discovery rate

the first test is a
Bonferroni correction at
level q

this means, if we have far too
many tests, FDR still can be non-
significant

the more significant points there
are, the higher is the p-value
cut-off

*if you include the time-window of
a very large effect (e.g., P3),
other effects may be significant*
Weak FWER control
Localization is difficult!

4. FDR

```
s1.PlotReg
s1.MaskPval
s1.fdr_q
s1.AddString
```

```
= [];
= 'fdr';
= 0.05;
= [' ' s1.UseValues ' group t fdr'];
```

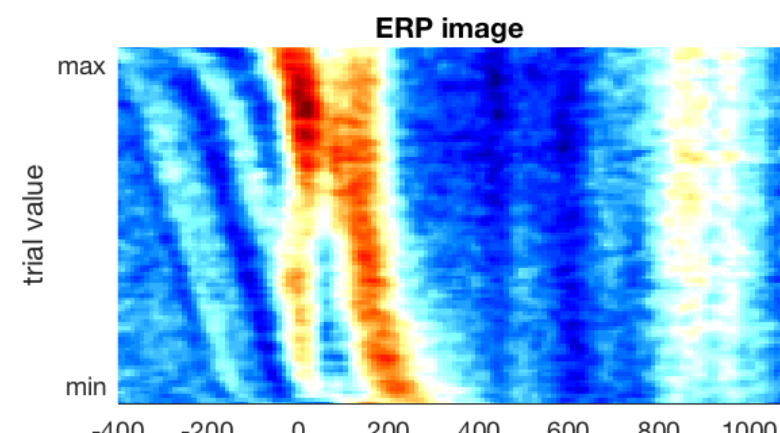
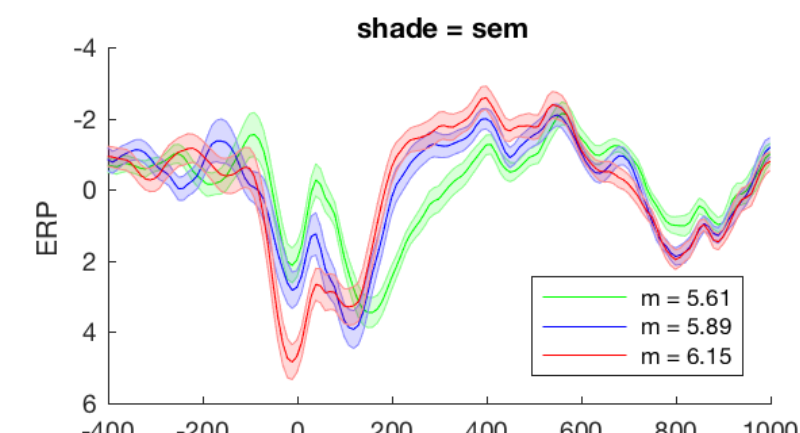
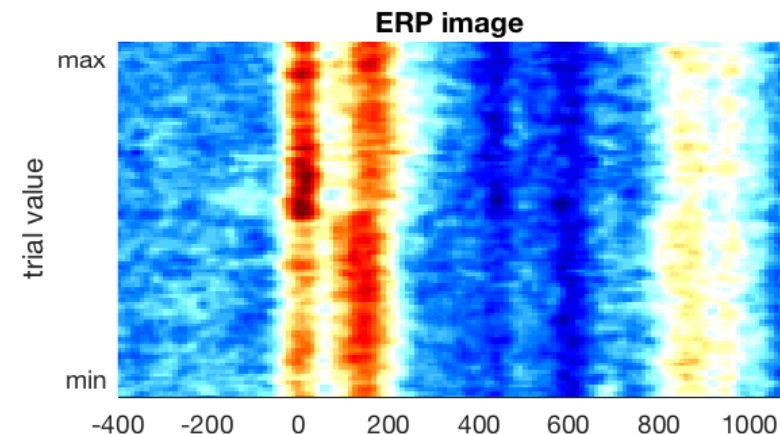
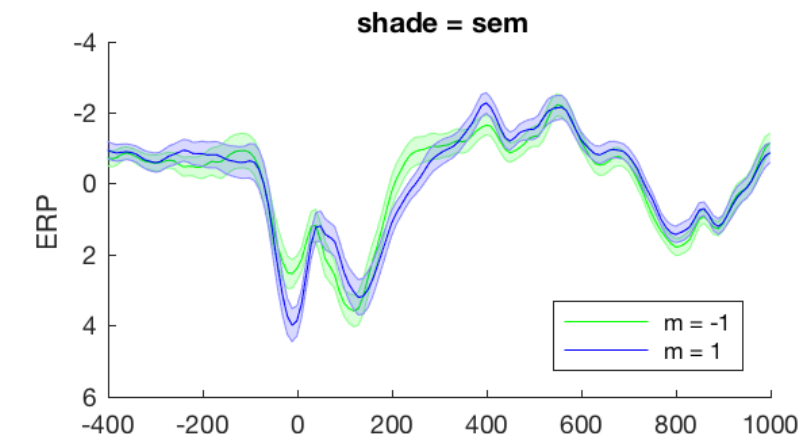
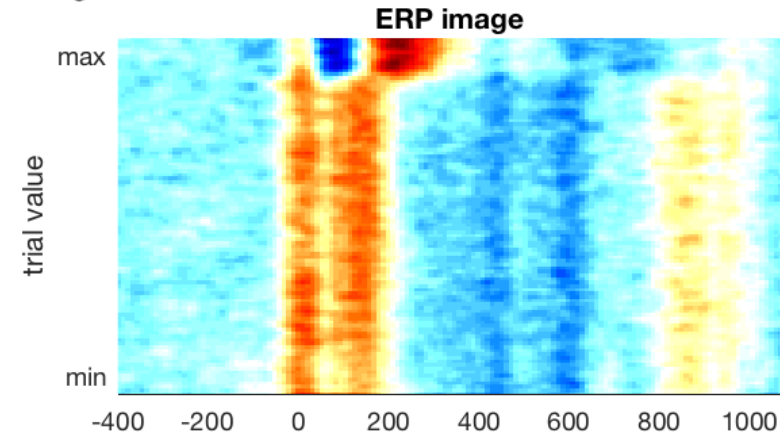
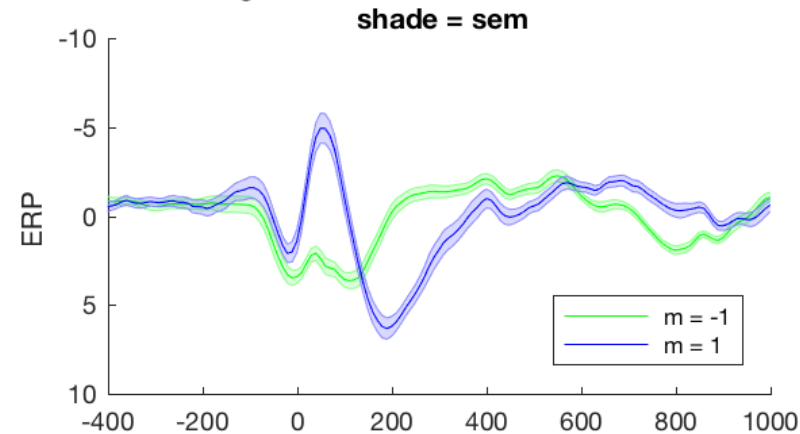
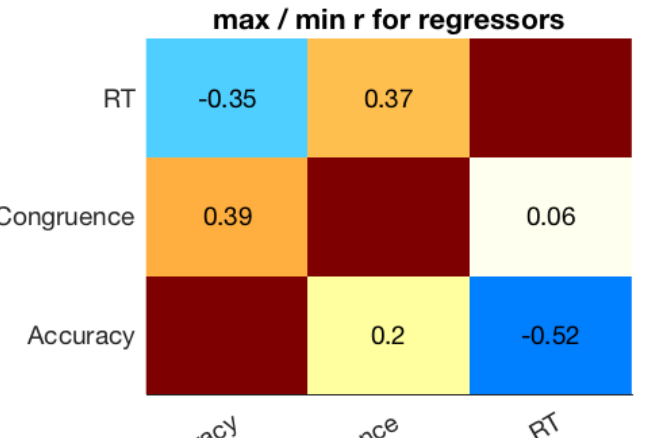
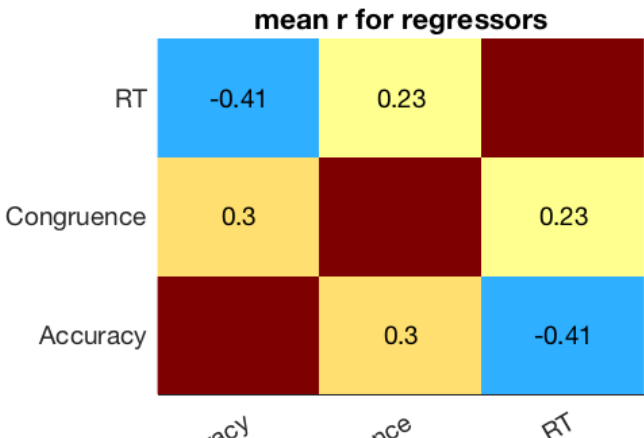
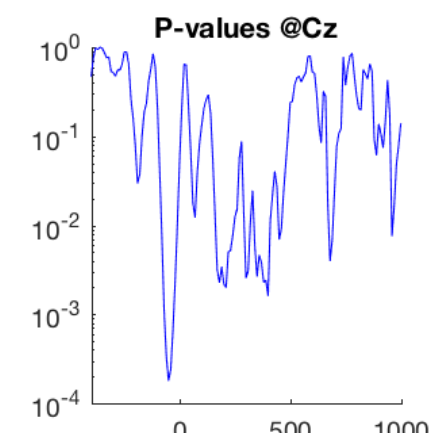
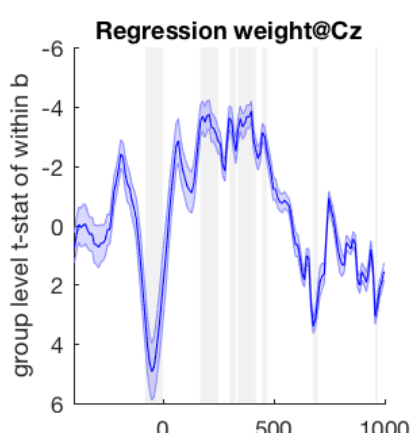
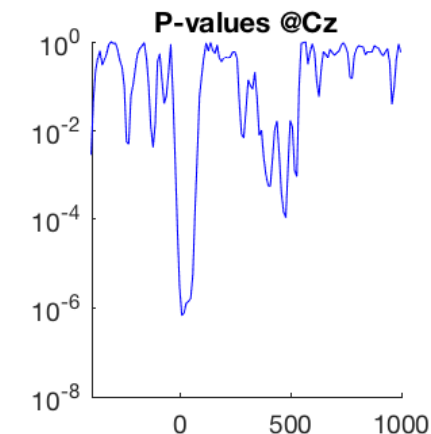
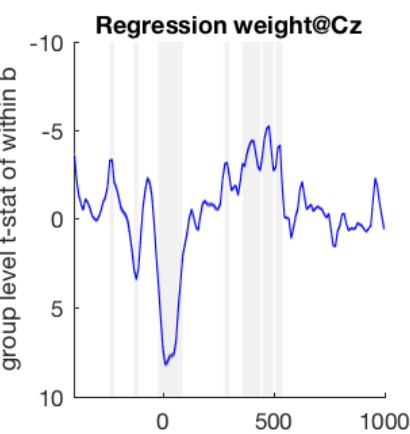
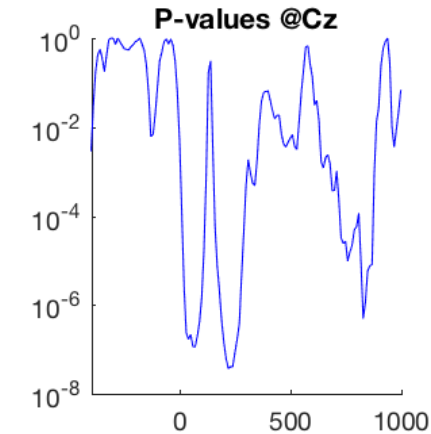
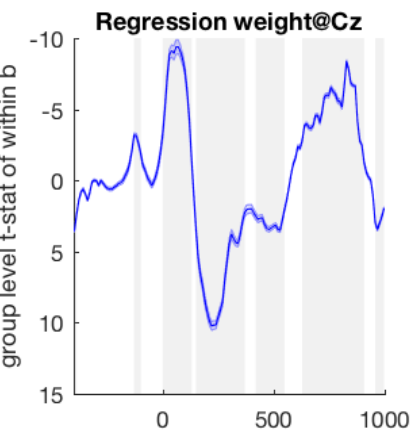
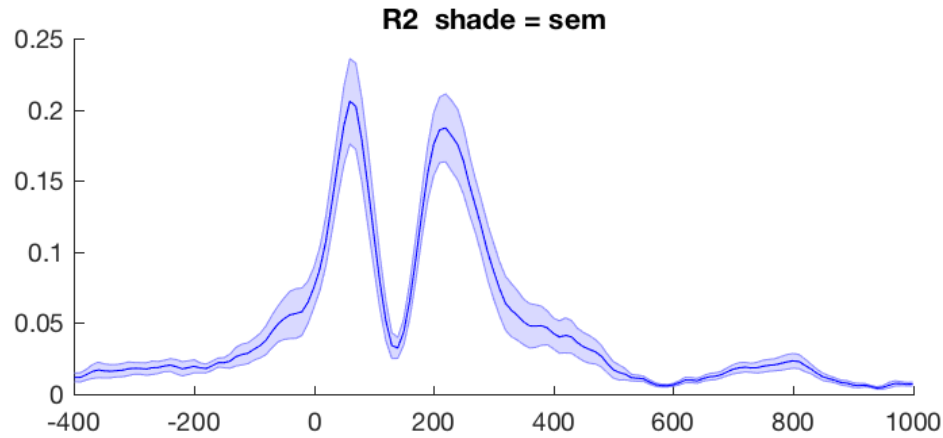
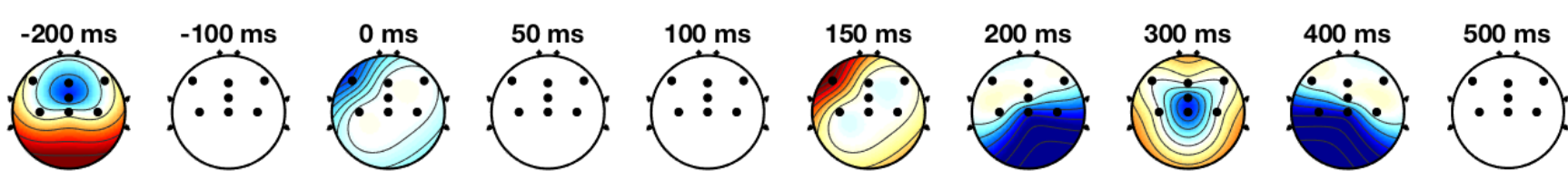
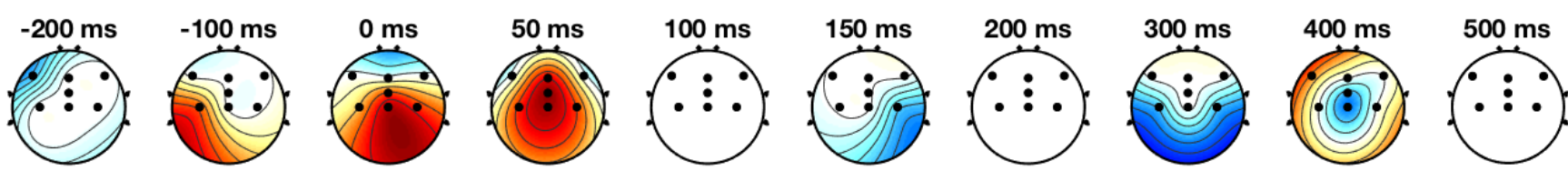
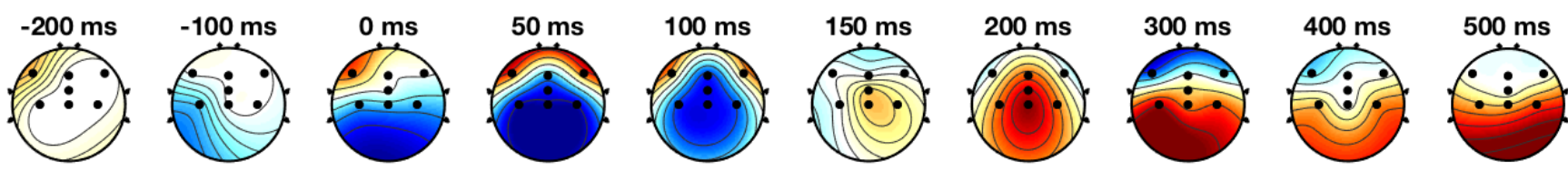
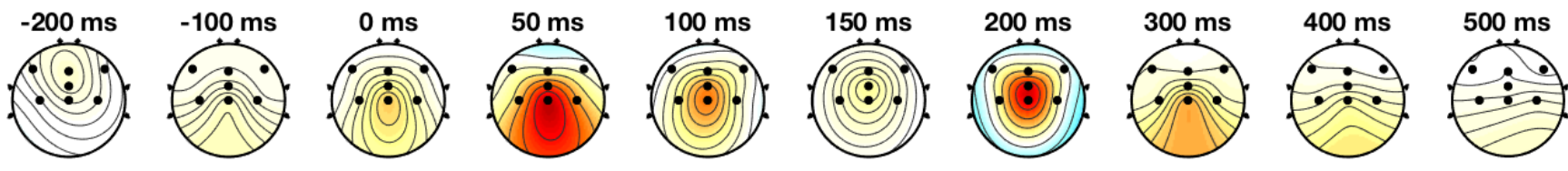
Overview at Cz for Simple Error Model b group t fdr

Overall R2
n subjects: 16
n Regressors 3
Min 0.004
Max 0.206 at 60 ms

Regressor: Accuracy
-1 = cor
1 = err
Maplimits -9.22 9.22
Maplimits -9.22 9.22
Crit p = 0.026896
Max 10.23 at 220 ms
Min -9.39 at 70 ms
p max = 3.70x10⁻⁸
p min = 1.13x10⁻⁷

Regressor: Congruence
-1 = con
1 = inc
Maplimits -7.93 7.93
Maplimits -7.93 7.93
Crit p = 0.011736
Max 8.16 at 10 ms
Min -5.21 at 480 ms
p max = 6.72x10⁻⁷
p min = 0.00010622

Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -4.96 4.96
Maplimits -4.96 4.96
Crit p = 0.01117
Max 4.94 at -50 ms
Min -3.84 at 400 ms
p max = 0.00017955
p min = 0.0016094



4.1 FDR with lower q

```
s1.fdr_q = 0.05 / 3;  
s1.AddString = [' ' s1.UseValues ' group t fdr q three regressors and elctrodes'];  
STA_Plot_Regression( [pathIn ModelName '/'], [pathPic ModelName], s1 )
```

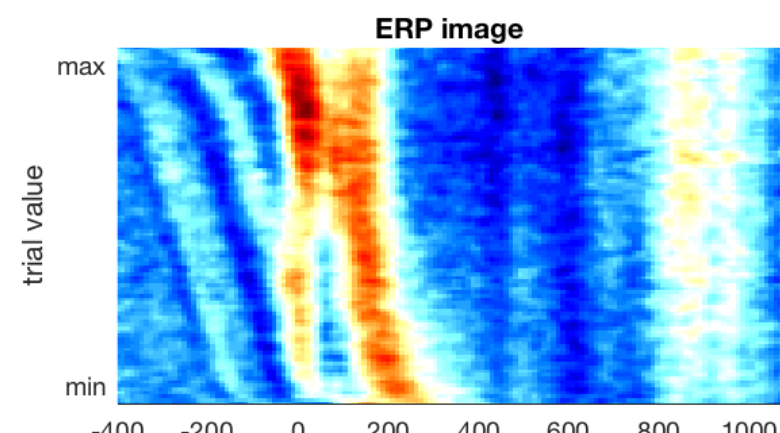
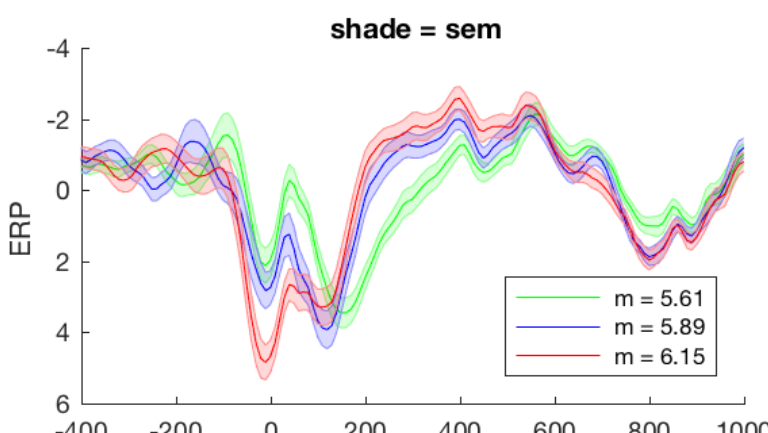
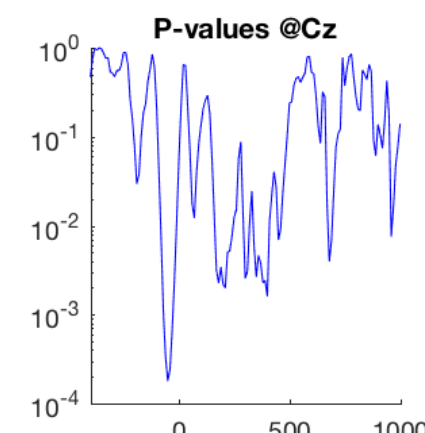
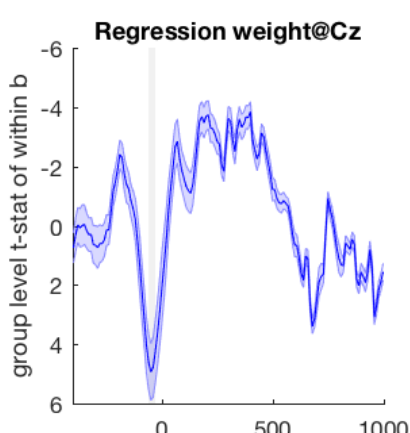
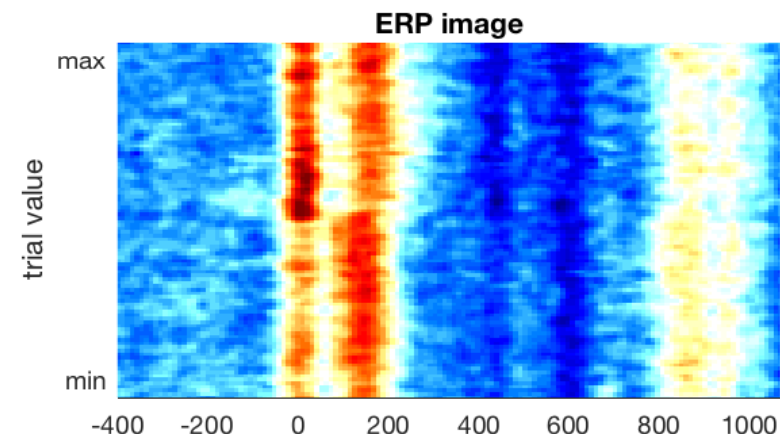
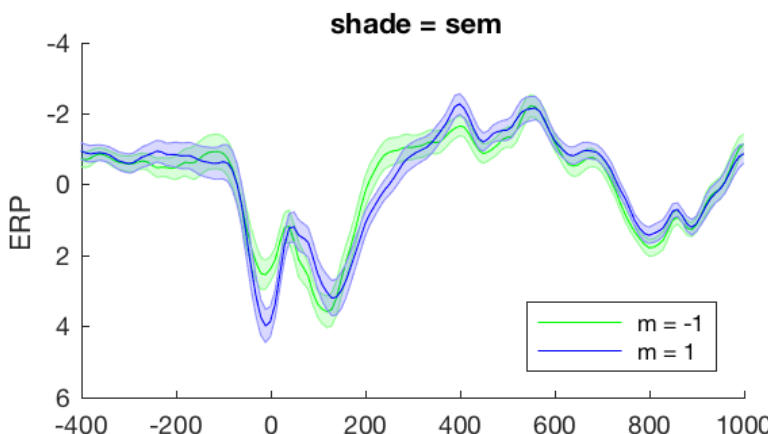
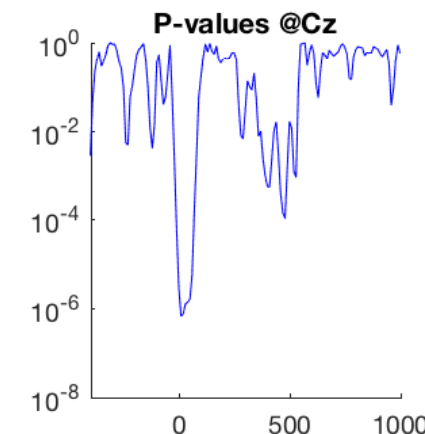
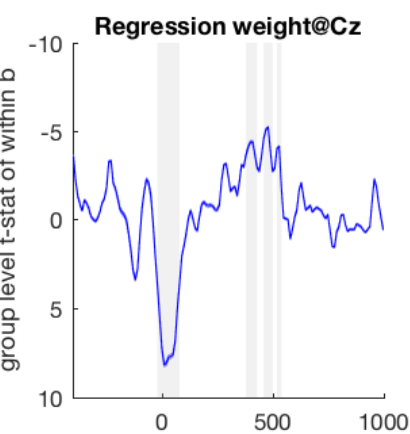
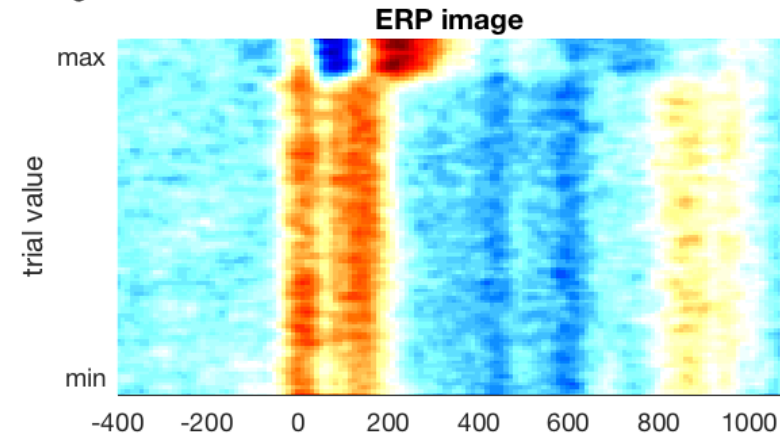
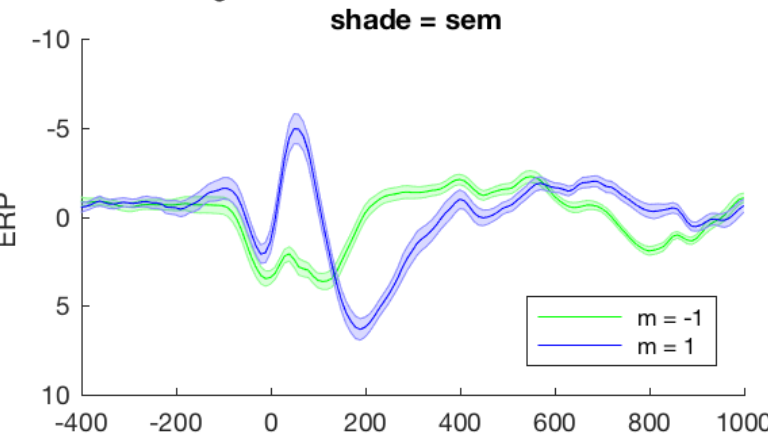
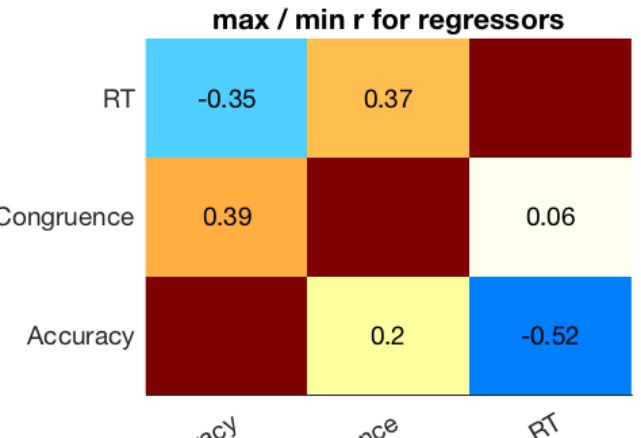
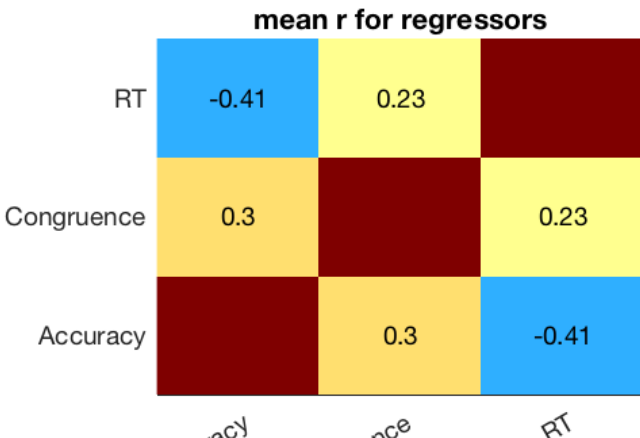
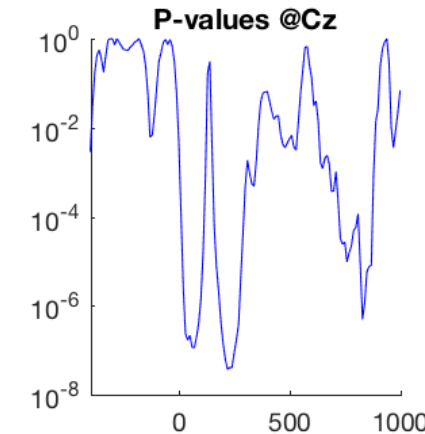
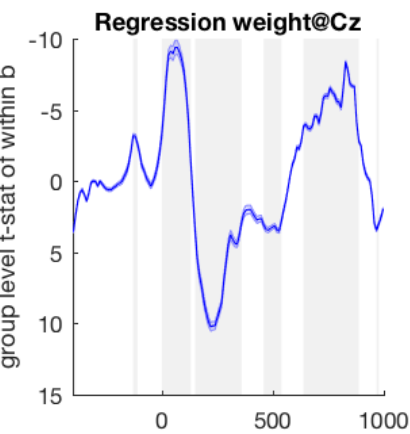
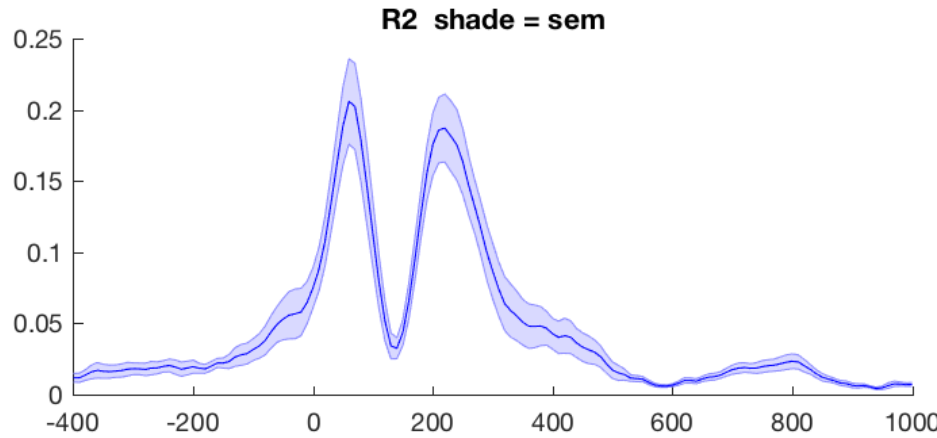
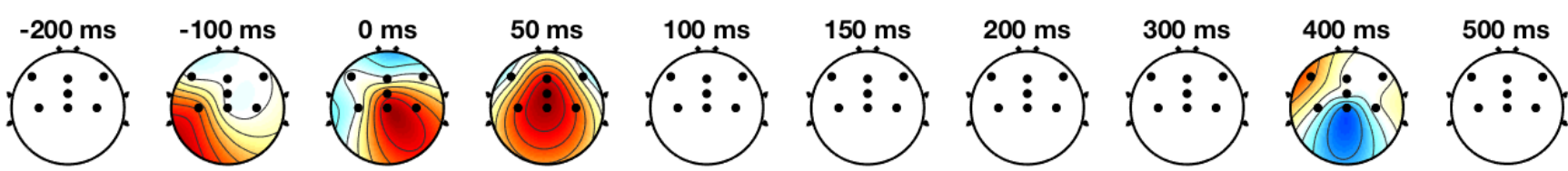
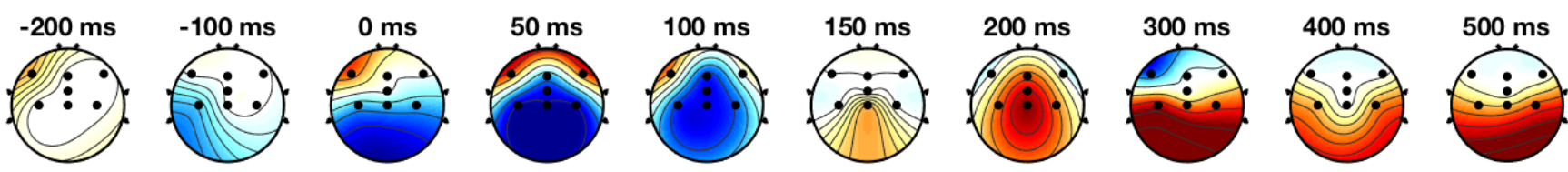
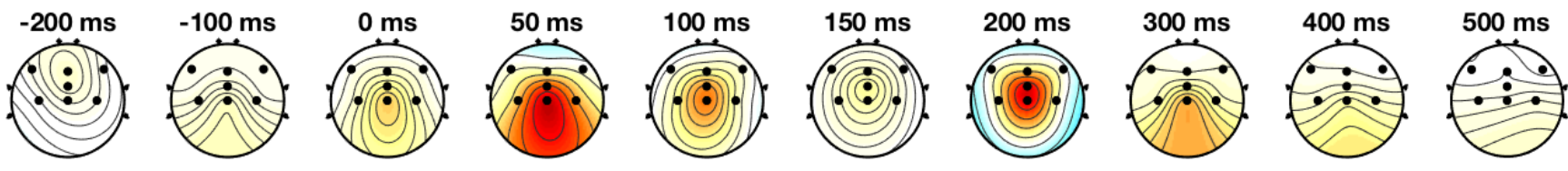
Overview at Cz for Simple Error Model b group t fdr q three regressors

Overall R2
n subjects: 16
n Regressors 3
Min 0.004
Max 0.206 at 60 ms

Regressor: Accuracy
-1 = cor
1 = err
Maplimits -9.22 9.22
Maplimits -9.22 9.22
Crit p = 0.0071536
Max 10.23 at 220 ms
Min -9.39 at 70 ms
p max = 3.70x10⁻⁸
p min = 1.13x10⁻⁷

Regressor: Congruence
-1 = con
1 = inc
Maplimits -7.93 7.93
Maplimits -7.93 7.93
Crit p = 0.0024367
Max 8.16 at 10 ms
Min -5.21 at 480 ms
p max = 6.72x10⁻⁷
p min = 0.00010622

Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -4.96 4.96
Maplimits -4.96 4.96
Crit p = 0.00033628
Max 4.94 at -50 ms
Min -3.84 at 400 ms
p max = 0.00017955
p min = 0.0016094

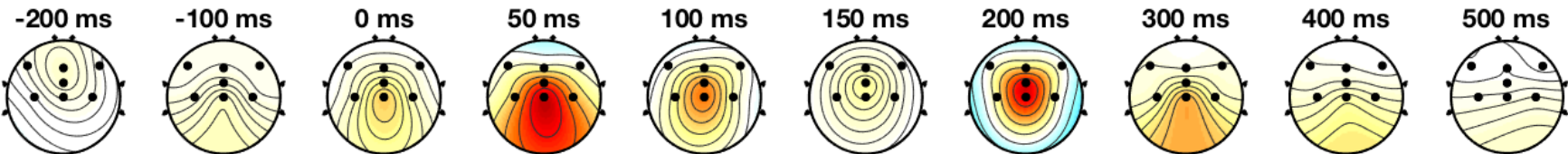


4.2 FDR with even lower q

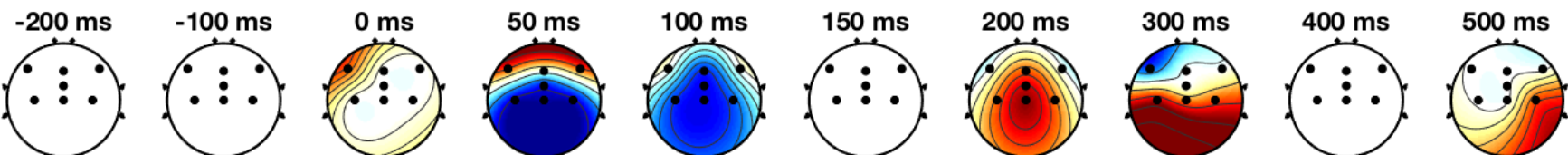
```
s1.fdr_q = 0.05 / (3 * 7);
s1.AddString = [' ' s1.UseValues ' group t fdr q three regressors and elctrodes'];
STA_Plot_Regression( [pathIn ModelName '/'], [pathPic ModelName], s1 )
```

Overview at Cz for Simple Error Model b group t fdr q three regressors and elctrodes

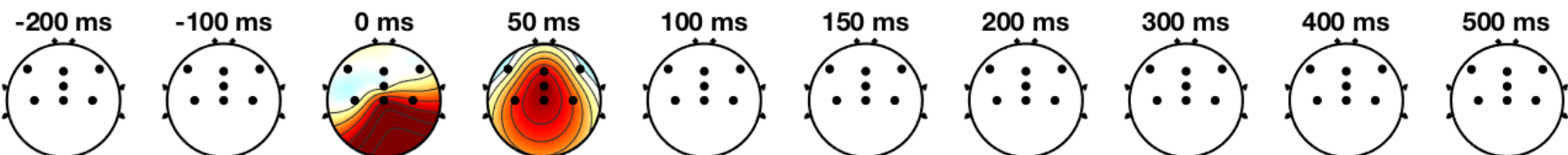
Overall R2
n subjects: 16
n Regressors 3
Min 0.004
Max 0.206 at 60 ms



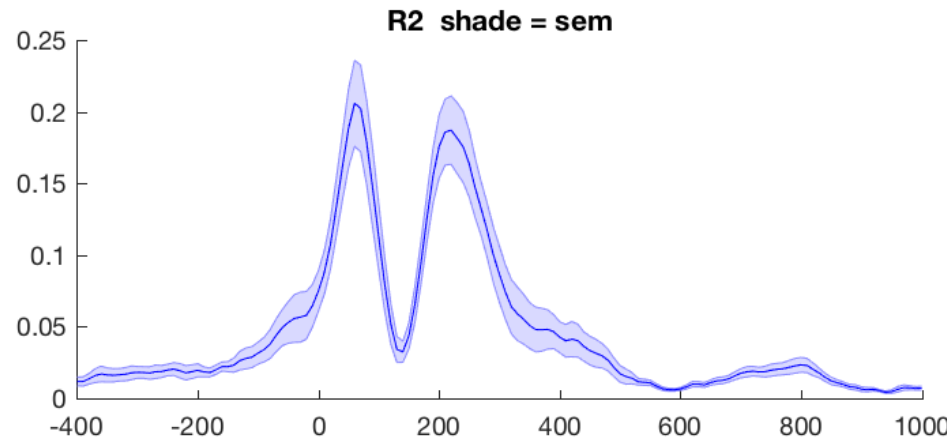
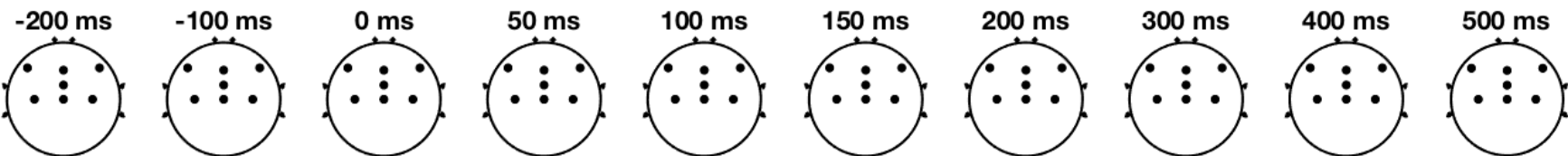
Regressor: Accuracy
-1 = cor
1 = err
Maplimits -9.22 9.22
Maplimits -9.22 9.22
Crit p = 0.00073803
Max 10.23 at 220 ms
Min -9.39 at 70 ms
p max = 3.70x10⁻⁸
p min = 1.13x10⁻⁷



Regressor: Congruence
-1 = con
1 = inc
Maplimits -7.93 7.93
Maplimits -7.93 7.93
Crit p = 0.0001663
Max 8.16 at 10 ms
Min -5.21 at 480 ms
p max = 6.72x10⁻⁷
p min = 0.00010622

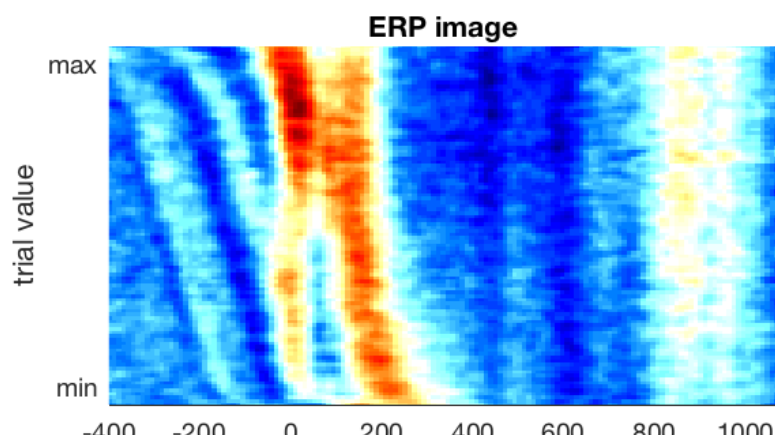
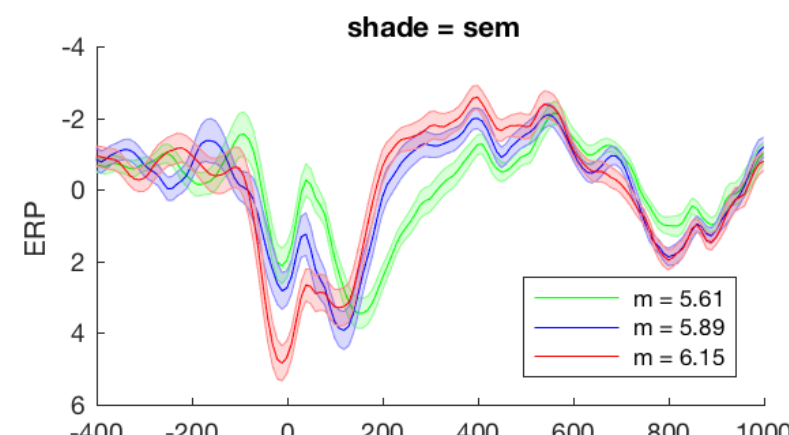
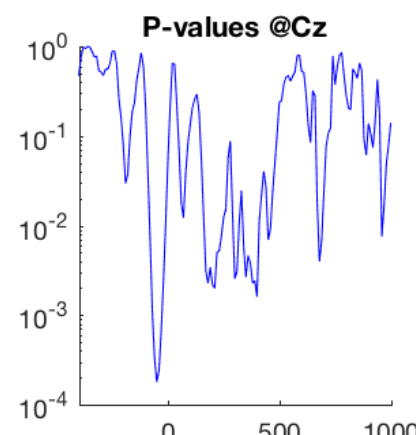
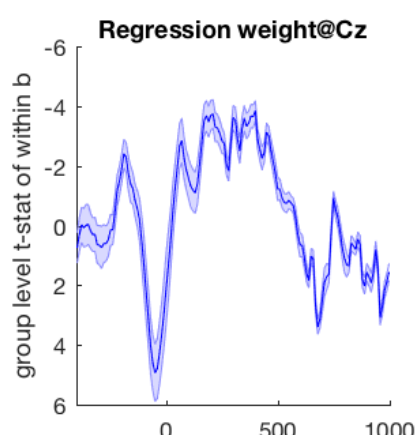
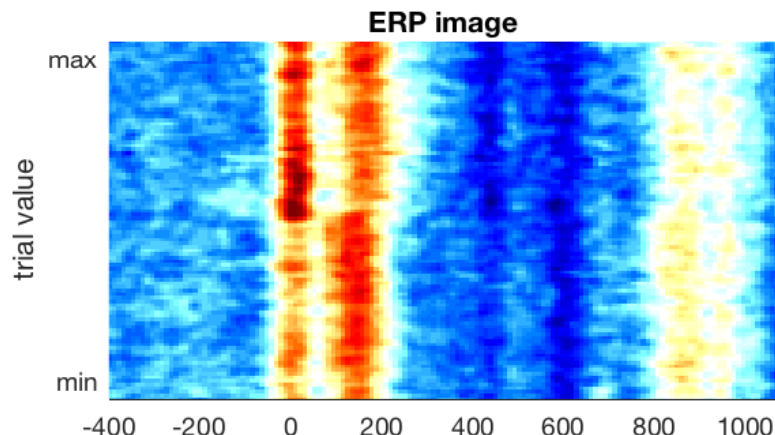
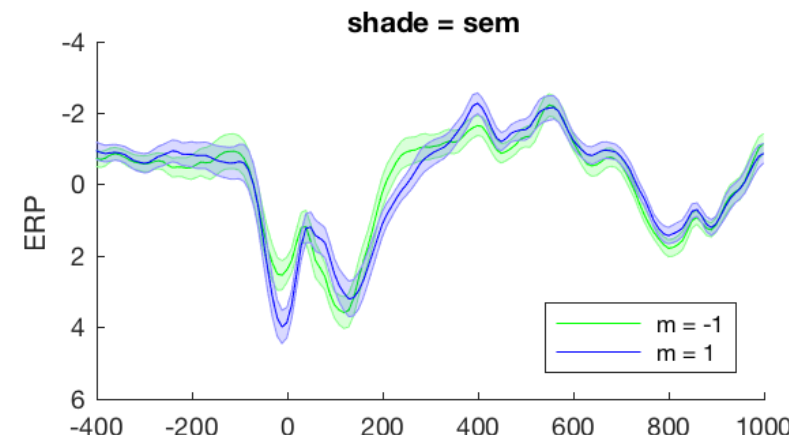
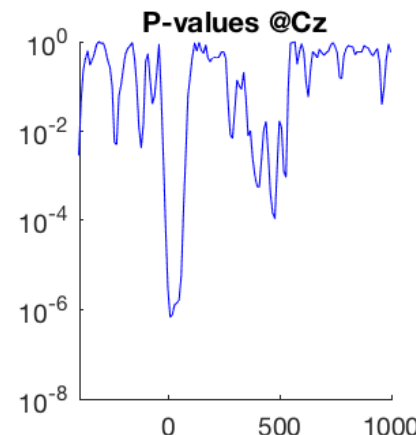
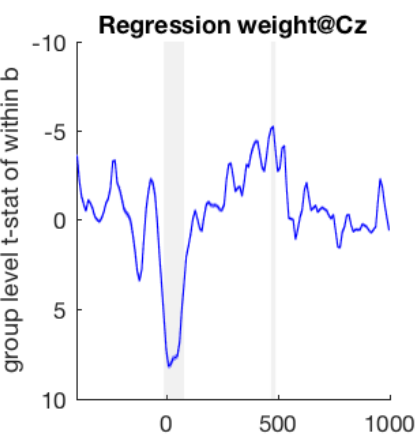
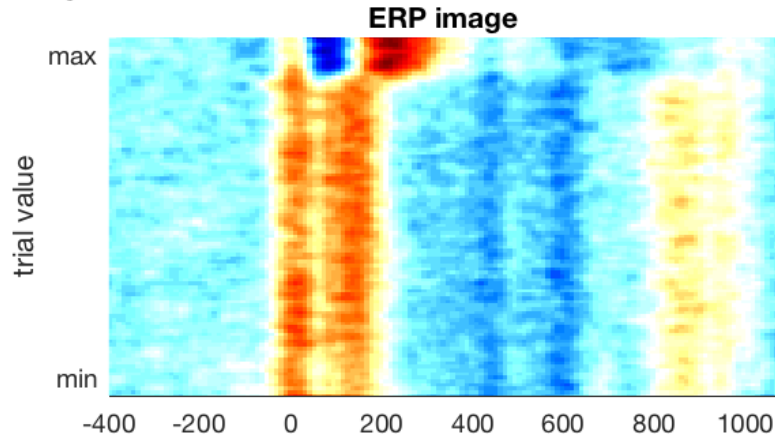
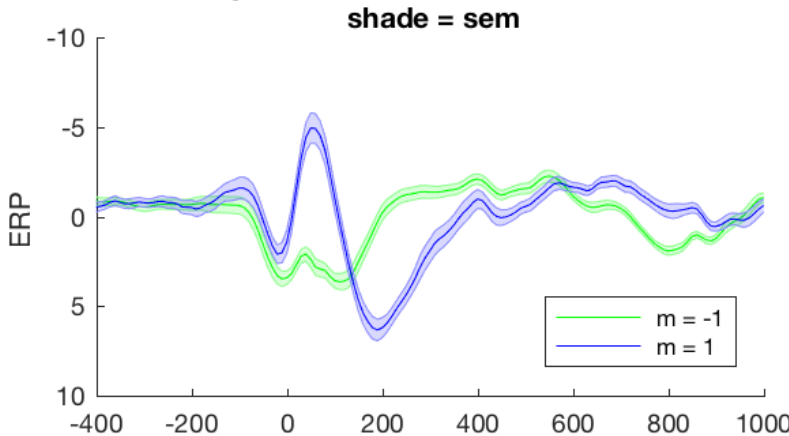
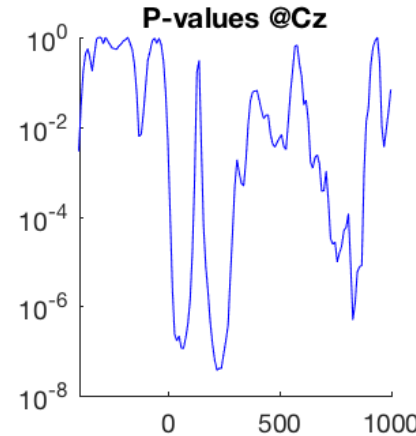
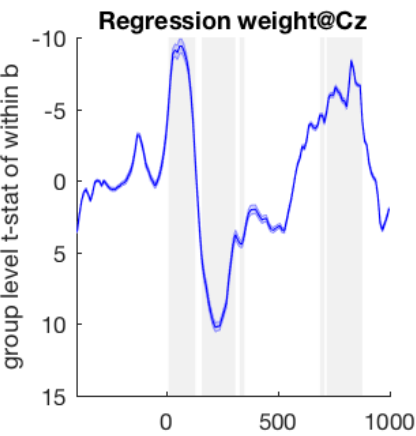


Regressor: RT
5.6082 = low
6.1516 = high
Maplimits -4.96 4.96
Maplimits -4.96 4.96
Crit p = 1.68x10⁻⁵
Max 4.94 at -50 ms
Min -3.84 at 400 ms
p max = 0.00017955
p min = 0.0016094



mean r for regressors		
RT	-0.41	0.23
Congruence	0.3	0.23
Accuracy	0.3	-0.41

max / min r for regressors		
RT	-0.35	0.37
Congruence	0.39	0.06
Accuracy	0.2	-0.52



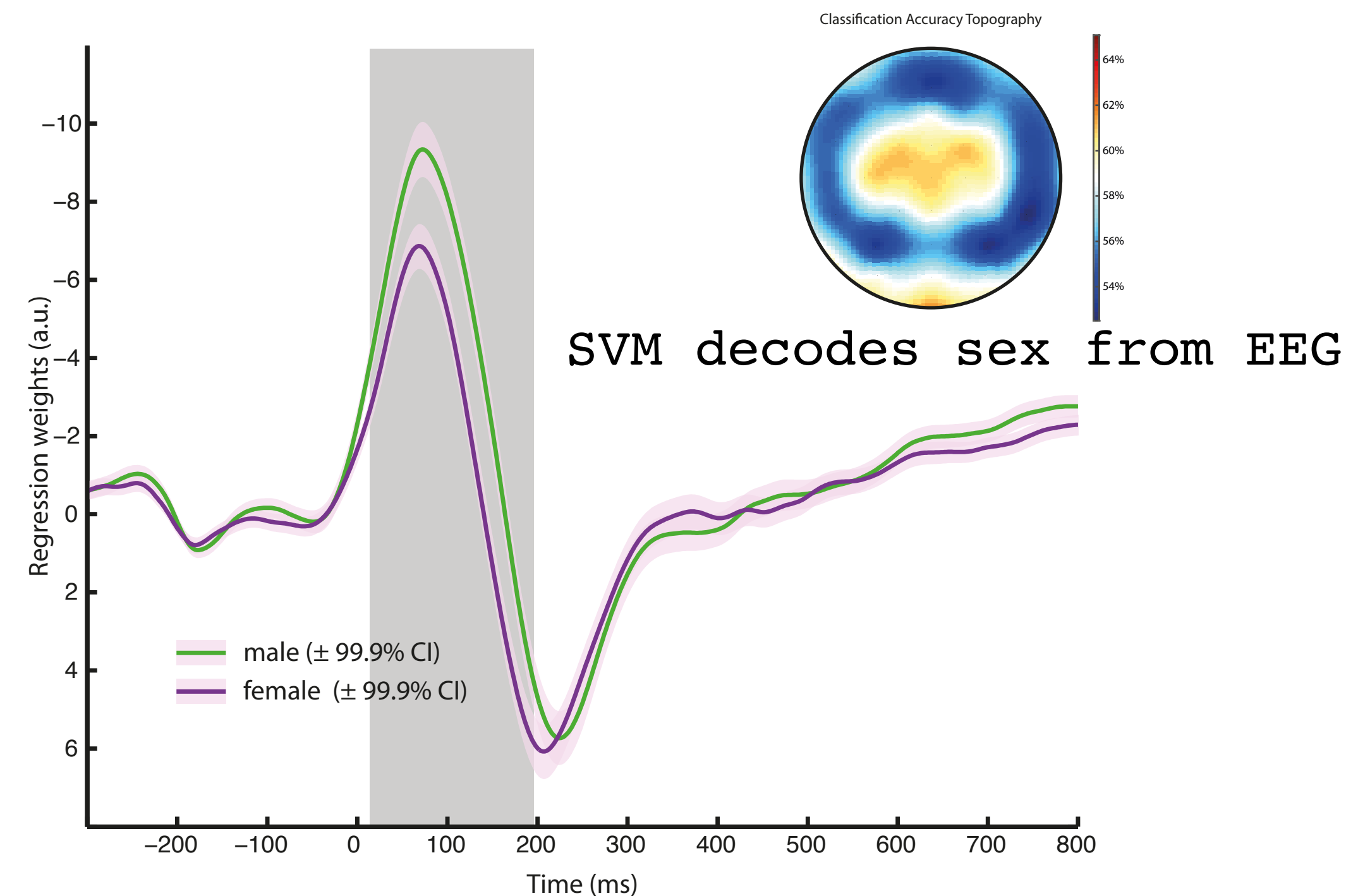
5. Comparing groups

```
pathPart= 'PartInfo/';
```

```
% Path to information about participant
```

- Just create separate plots for two groups:
 - male (n = 4)
 - female (n = 12)
 - ➔ relatively typical for the population of psychology students!
- We want to:
 - plot average within participant b-values
 - for regressor accuracy (accounted for RT & congruence)
 - with associated scalp topographies
 - assess R^2 in both groups over time
 - use FDR with false discovery rate accounting for all electrodes
 - ➔ easy!

larger ERN in male participants
(while controlling for RT within,
and across participants)



5. Comparing groups

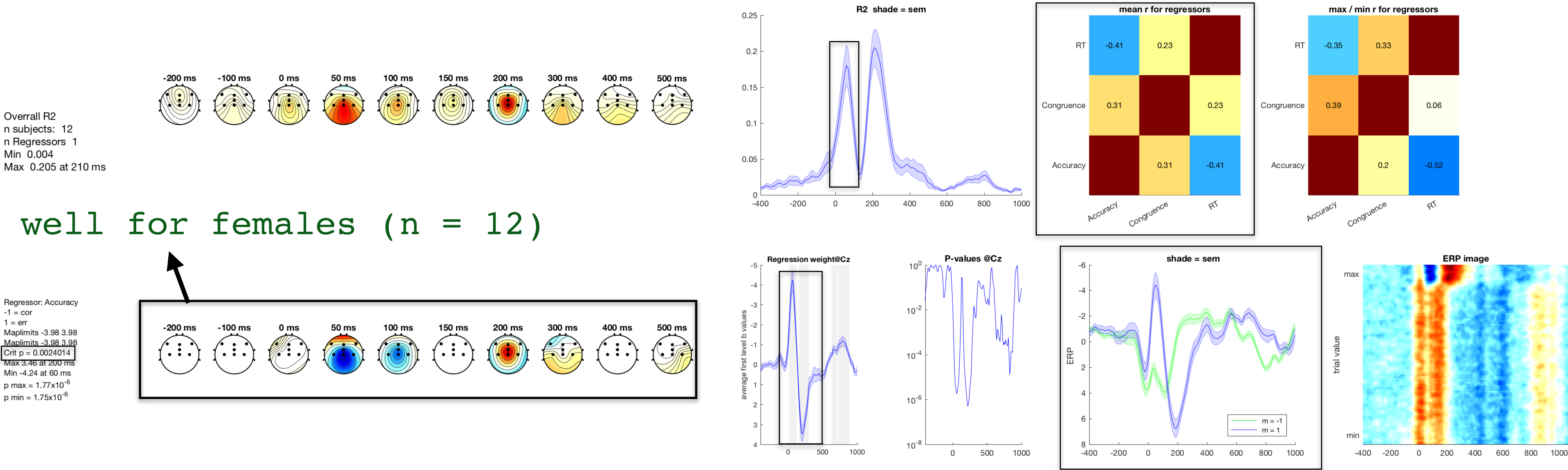
```
s2.MaskPval      = 'fdr';      %use FDR
s2.fdr_q         = 0.05 / 7;  %set false discovery rate
s2.GroupStats    = 0;         %we want to plot average within participant effects!
s2.UseValues     = 'b';       %we want regression weights
s2.PlotReg       = [1];       %we only want the first regressor (accuracy)

s2.Groups        = {[find(sex==1)]';[find(sex==2)]'}; %use sex to define male and female groups
s2.GroupNames    = {'male' 'female'}; %provide a name for the groups
s2.AddString     = [' ' s1.UseValues ' group t fdr electrodes'];

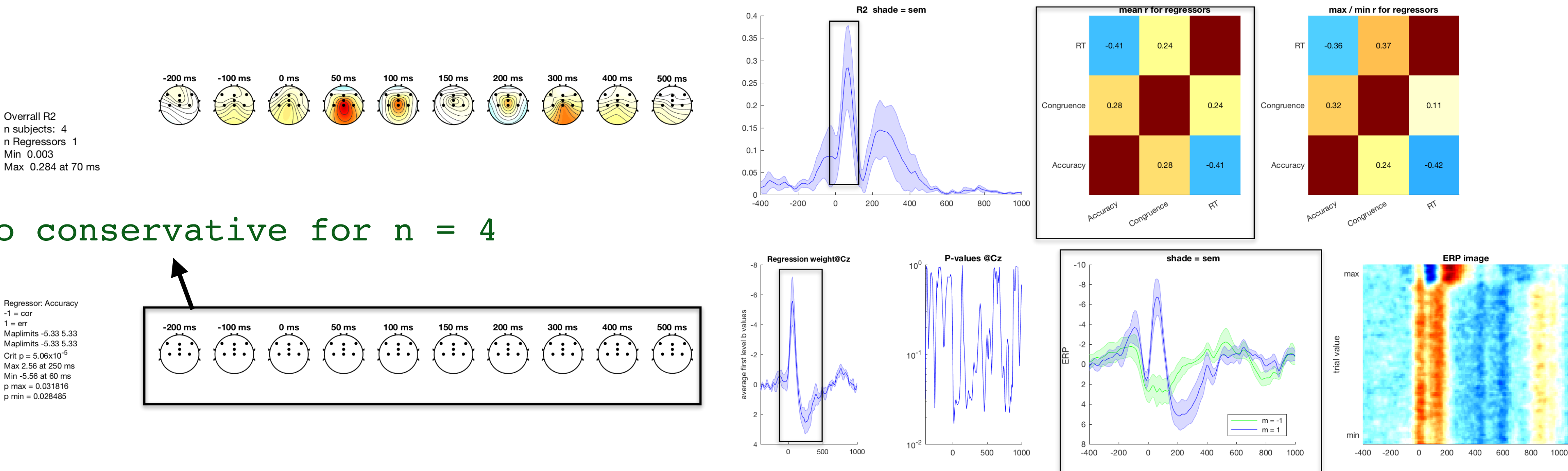
STA_Plot_Regression( [pathIn ModelName '/' ], [pathPic ModelName], s2 )
```

5. Comparing groups

Overview at Cz for Simple Error Model in group female b group t fdr electrodes



Overview at Cz for Simple Error Model in group male b group t fdr electrodes



5.2 Contrast effects across groups

- Apart from just looking at two separate groups, most of us will likely want statistics to compare between groups
- So what we actually want:
 - ▶ statistically compare within participant b - or t -values between male and female subjects for regressor accuracy
 - ▶ with associated scalp topographies of these differences
 - ▶ account for possible confounds (age, parametric variable)
 - ▶ (use FDR with false discovery rate accounting for all electrodes)
 - ➡ easy!

5.2 Contrast effects across groups

```
DM_2ndL = table(sex, age) %make a table from the variables

s2.UseValues      = 't'; %use t values
s2.ModelName      = 'workshop_model'; %name for the 2nd level model
s2.RegLables      = [{'male' 'female'}; {'younger' 'older'}]; %lables
s2.UseReg         = 1; %reduce to effects of accuracy regressor alone

STA_2nd_Level_Regression([pathIn ModelName '/' ], DM_2ndL, s2) %run second level model
```

- we can use the same plot function as before, but modify the settings a bit:

```
infol = [pathIn ModelName '/2ndlevel/workshop_model/']; %the output path from before
F      = dir([infol '*.mat']); %find the output files --> 'workshop_model Accuracy.mat'

sp2.plotsteps      = [-200 -100 0 50 100 150 200 300 400 500];
sp2.plotelect      = 'Cz';
sp2.FileName       = F(1).name; %set this as the input file name
sp2.MaskPval       = 0.3; %we want to see the topographies well, so we use a low threshold
sp2.Level         = 2; %define that this is a 2nd level statistic plot
sp2.ERP_Im_plot     = 1; %plot an ERP image (these are so to say within subject averages!)
sp2.ExtrapoS       = length(age); %overwrite default extrapolation setting to number of subjects for ERP image
sp2.ERPimageSm      = 5; %because ERP image is average subject data, we do not want to smooth this too much
```

```
STA_Plot_Regression( infold, [pathPic ModelName], sp2 )
```

5.3 Results

not really significant,
but larger (more negative)
t in male participants

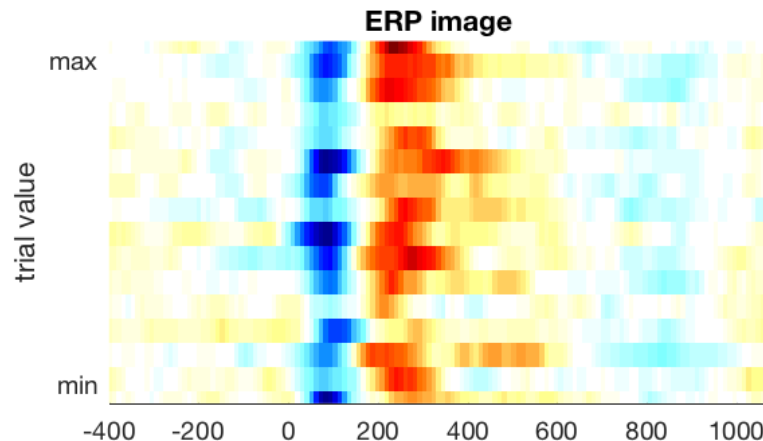
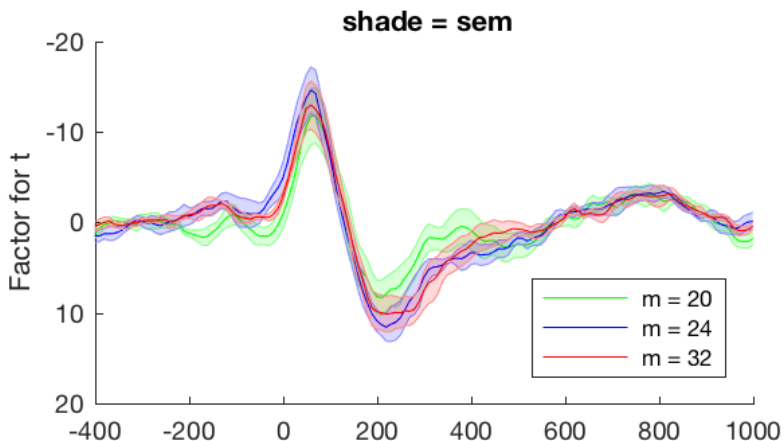
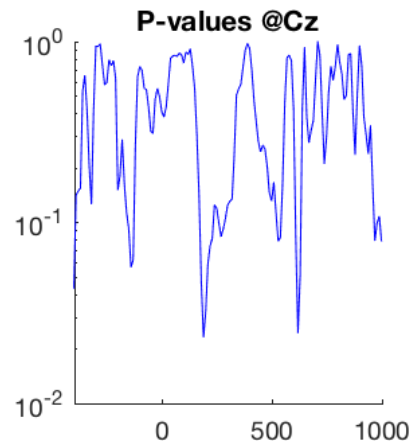
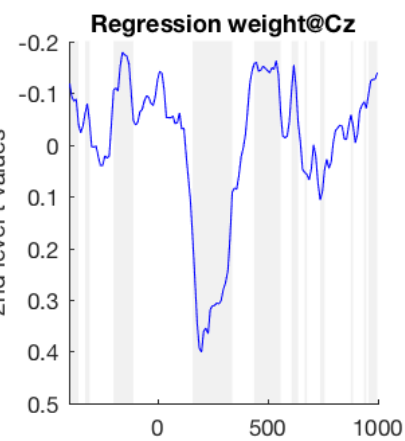
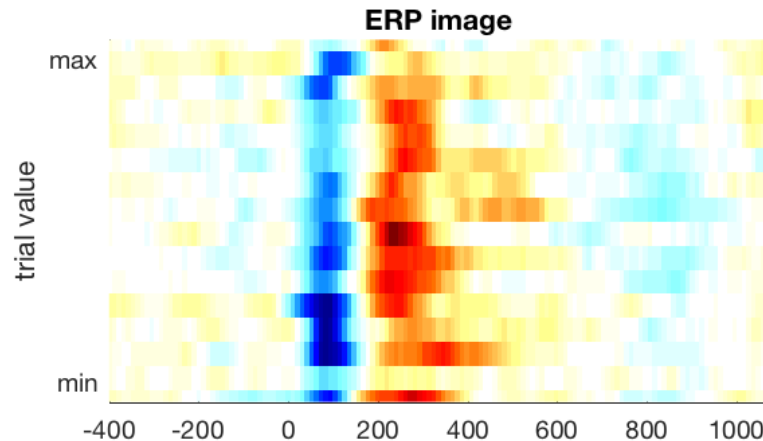
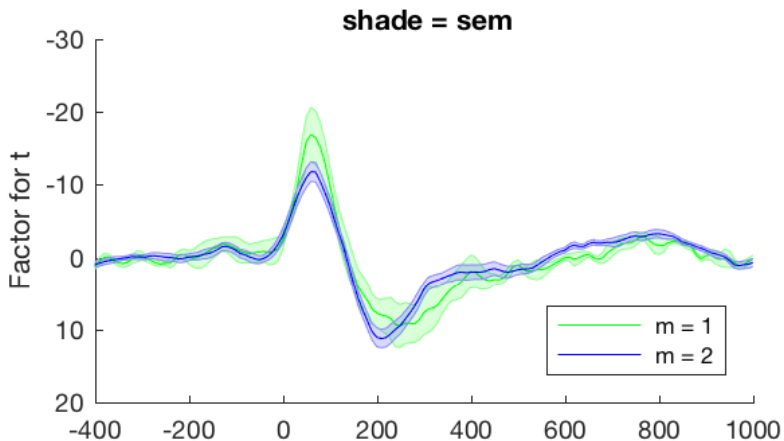
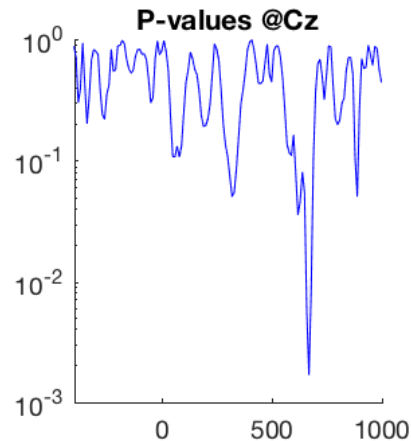
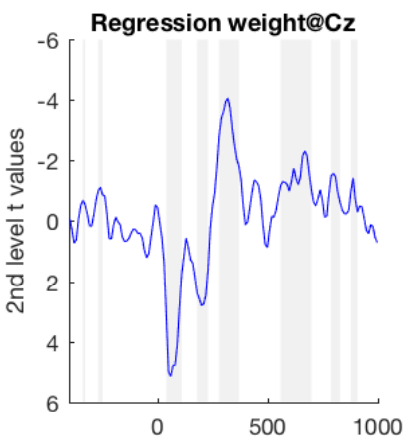
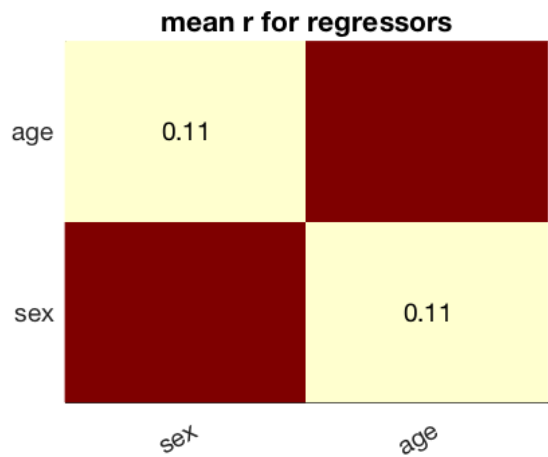
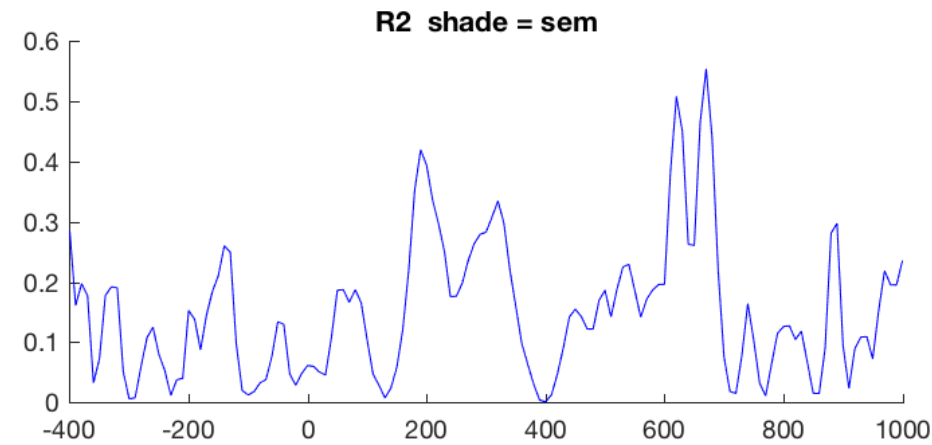
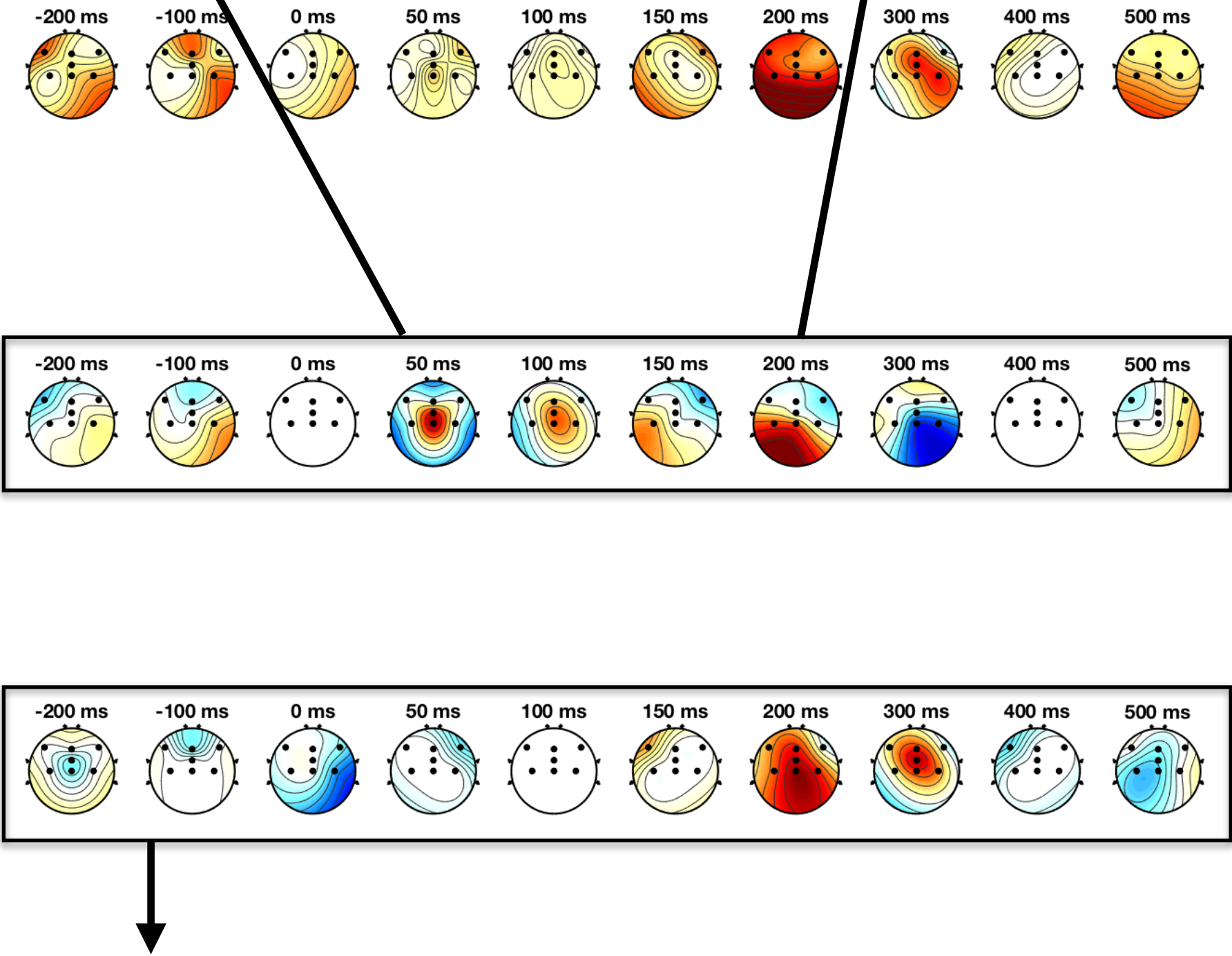
Pe might be a bit larger
or peak earlier
in females

Overview at Cz for Accuracy 2nd Level Regression Model for workshop model

Overall R2
n subjects: 16
n Regressors 2
Min 0.001
Max 0.554 at 670 ms

Regressor: sex
1 = male
2 = female
Maplimits -5.01 5.01
Maplimits -5.01 5.01
Crit p = 0.3
Max 5.16 at 60 ms
Min -4.06 at 320 ms
p max = 0.10733
p min = 0.050481

Regressor: age
minsplit: 20.2
maxsplit: 31.5
Maplimits -0.4 0.4
Maplimits -0.4 0.4
Crit p = 0.3
Max 0.4 at 200 ms
Min -0.18 at -160 ms
p max = 0.031965
p min = 0.11306



age (in the range of this sample)
does not affect error signals
at Cz systematically

- t -test and 2nd level regression models are valid ways to compare results of within-subject regression b -values and (at least with larger samples) t -values
- 2nd level regression provides an easy way to control for between-subject confounds and test more complicated hypotheses
- FDR is an established way to control false positives, but one needs to be aware of some caveats (weak correction of FWER!)