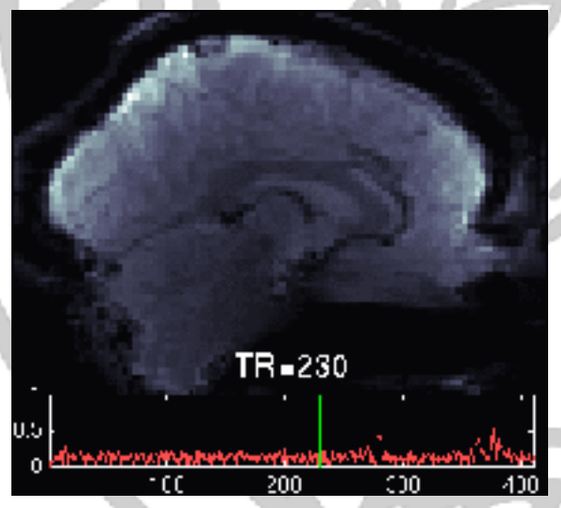
Assessment of “denoising” (motion artifacts removal) on resting state fMRI data



Method Club
2015-10-15
Seung-Goo (“SG”) KIM

Questions to discuss today

1. Why do you want to ‘modify’ your data?
2. If you do it, how can you tell it’s improved or worsened?
3. Which parameters work better than others?

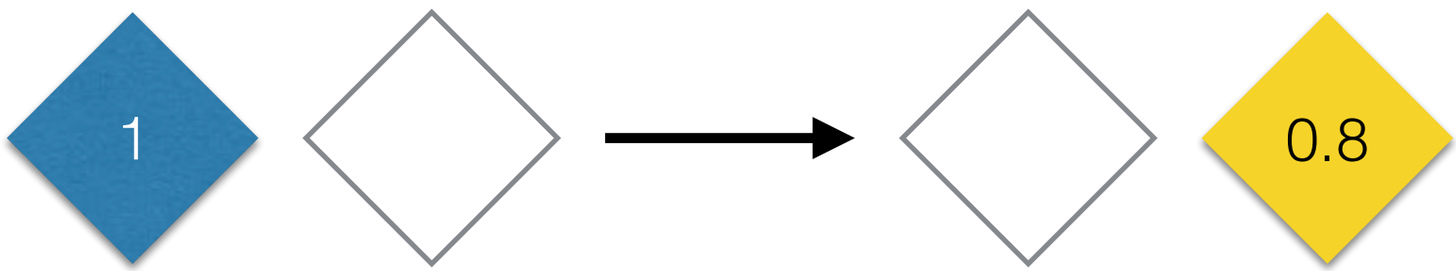
*DISCLAIMER: This is not to defend/recommend a certain toolbox (e.g. CONN) but to openly discuss about the assessment of denoising process for rs-fMRI!

Question #1

- Why do we have to “modify” our data?
- Because head motion does not only change the position, but also change IMAGE INTENSITY too!
- Head motion particularly creates ***synchronized signal change***, which results in heightened correlation over nearby (and also distant) voxels.

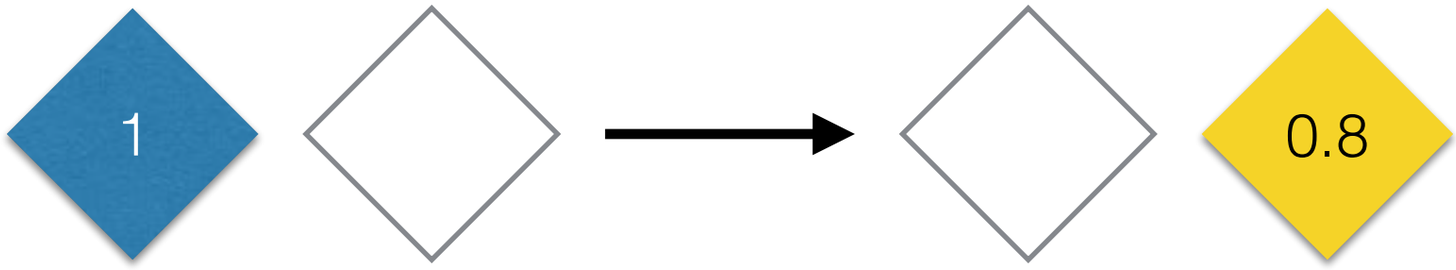
Why signal changes?

in k-space:



1 TE 2 TE

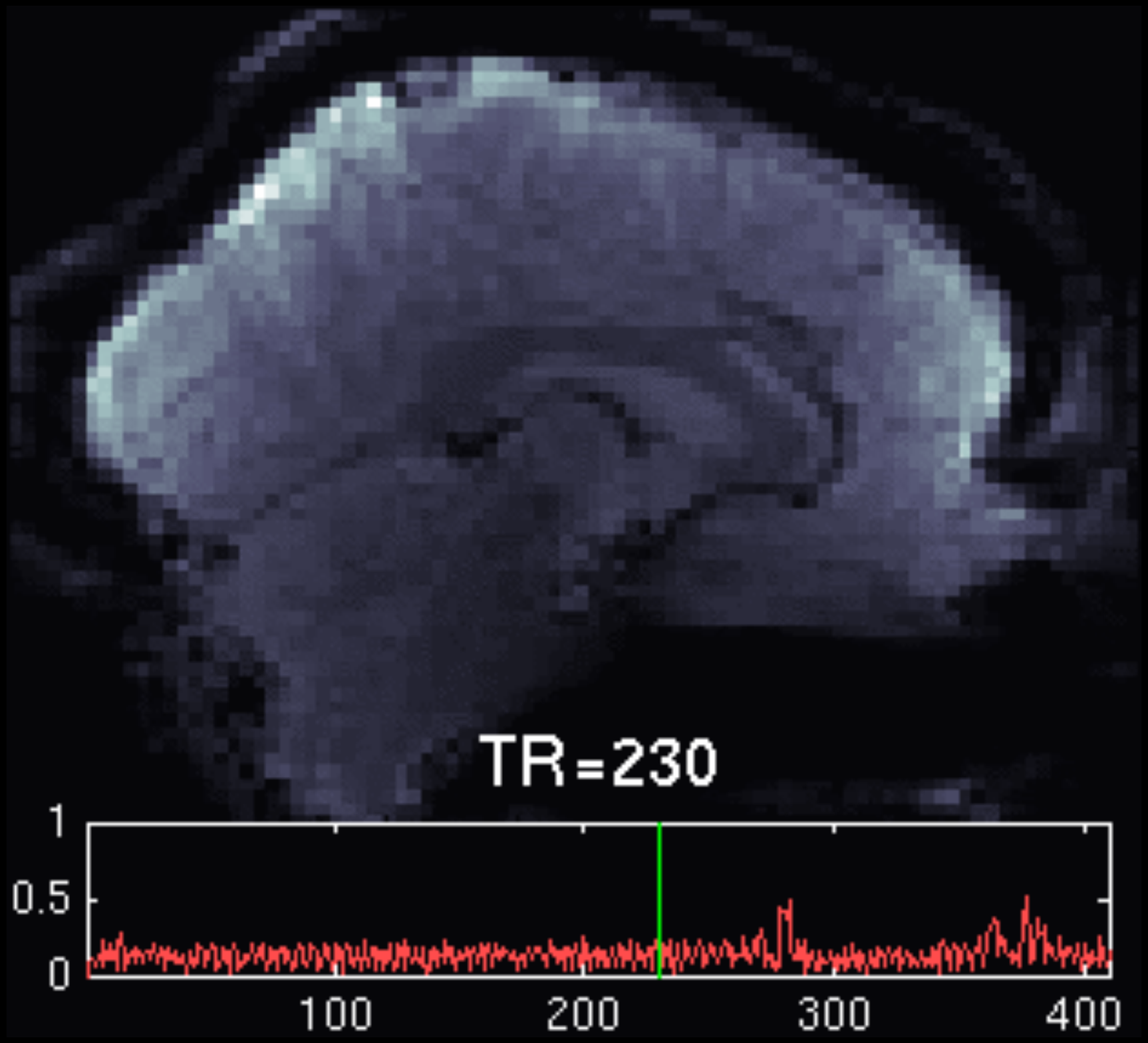
in k-space:



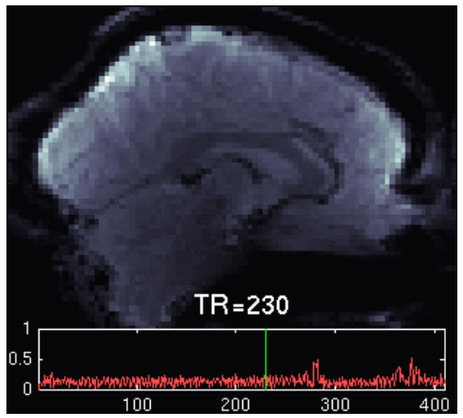
1 TE 2 TE

Example

- MAGNETOM Prisma at 3-T
    - 4x multiband EPI sequence of 64 axial slices with 88 x 88 image matrix (“LEMON” sequence)
        - TR/TE= 1400/30 msec; FA= 69 degrees
        - 420 volumes (9.8 min)
        - Voxel size= 2.295 x 2.295 x 2.300 mm^3
- Subject: a healthy male musician (German)


TR=230
1
0.5
0
100
200
300
400

even after realignment



/scr/vatikan3/APConn/rest12.410/2001/uarest410.nii

$||dm/dt||_2$(mm)

1
0.5
0
50 100 150 200 250 300 350 400

x 10^4

2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2

GM>0.99 voxels

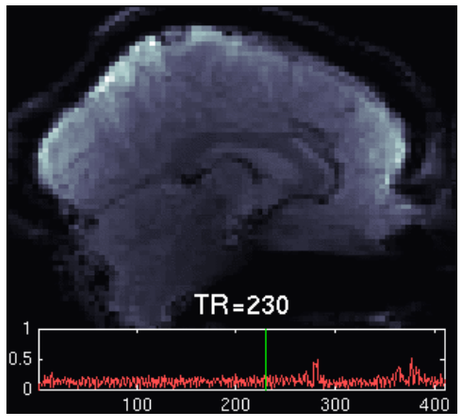
50 100 150 200 250 300 350 400

x 10^4

2
1.5
1
0.5
0

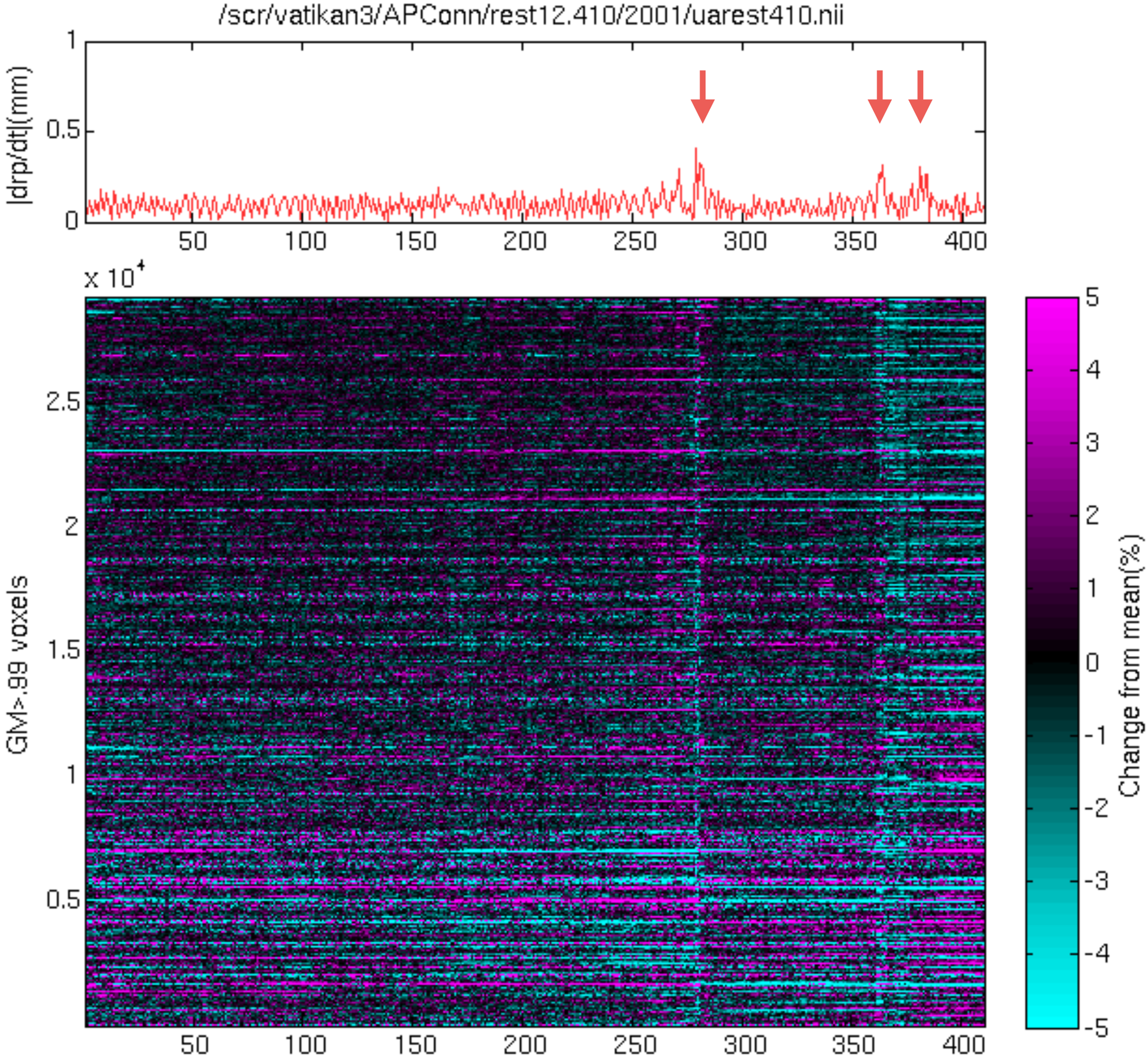
Image intensity

Image Intensity



Signal change from mean:

$$\frac{x(t) - \bar{x}}{\bar{x}}$$



Question #2

- How can we tell whether some signal is induced by head motion or neural activities?

- We (I) assume:
  - head movements affects extensively (global signal)
  - WM/CSF voxels doesn't show neuronal hemodynamics but motion-induced signal change (CompCor)
  - correlation between random GM voxels would be close to Gaussian, at least under the null model (K-S test)

Theory

Trend & rigidbody motion

Physiological (non-neuronal) noise

Unexplained signal (hopefully intrinsically structured)

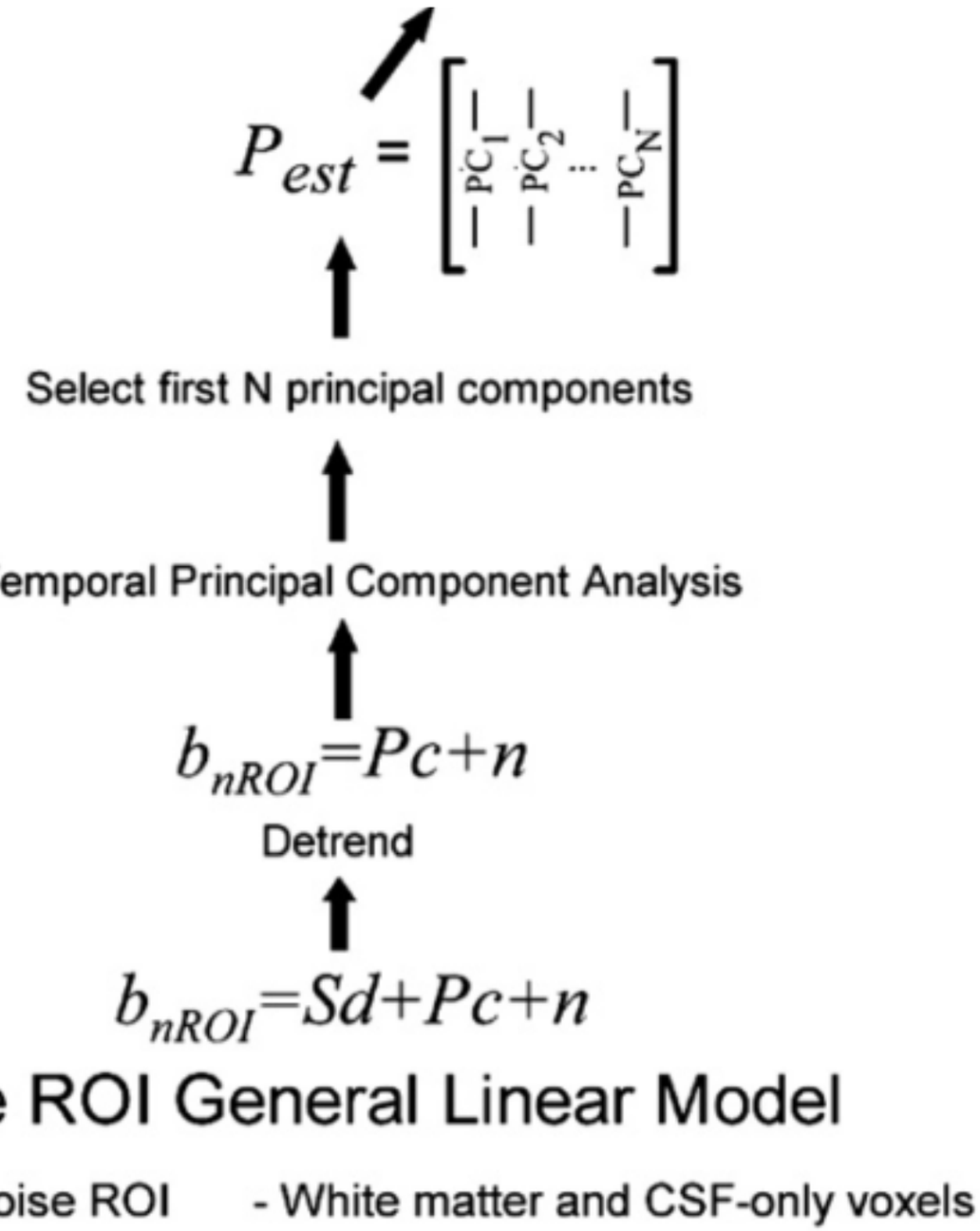
$$b_{gray} = Sd + Pc + Gd + Ce + n$$

Global signal

Censoring (scrubbing)

(modified from Behzadi et al., 2007, NI.)

Physiological noise?



Behzadi et al., 2007. NI

“Denoised” timeseries

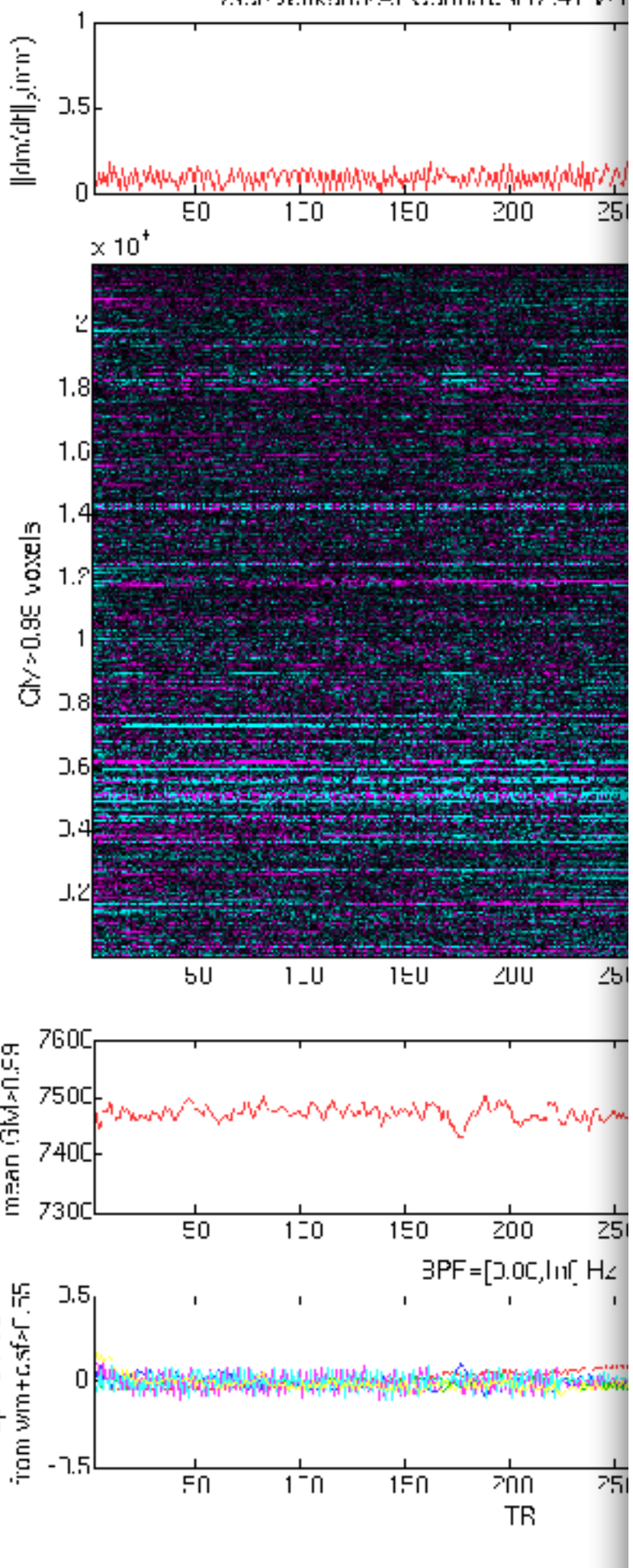
$$b_{gray} = Sd + Pc + Gd + Ce + n$$

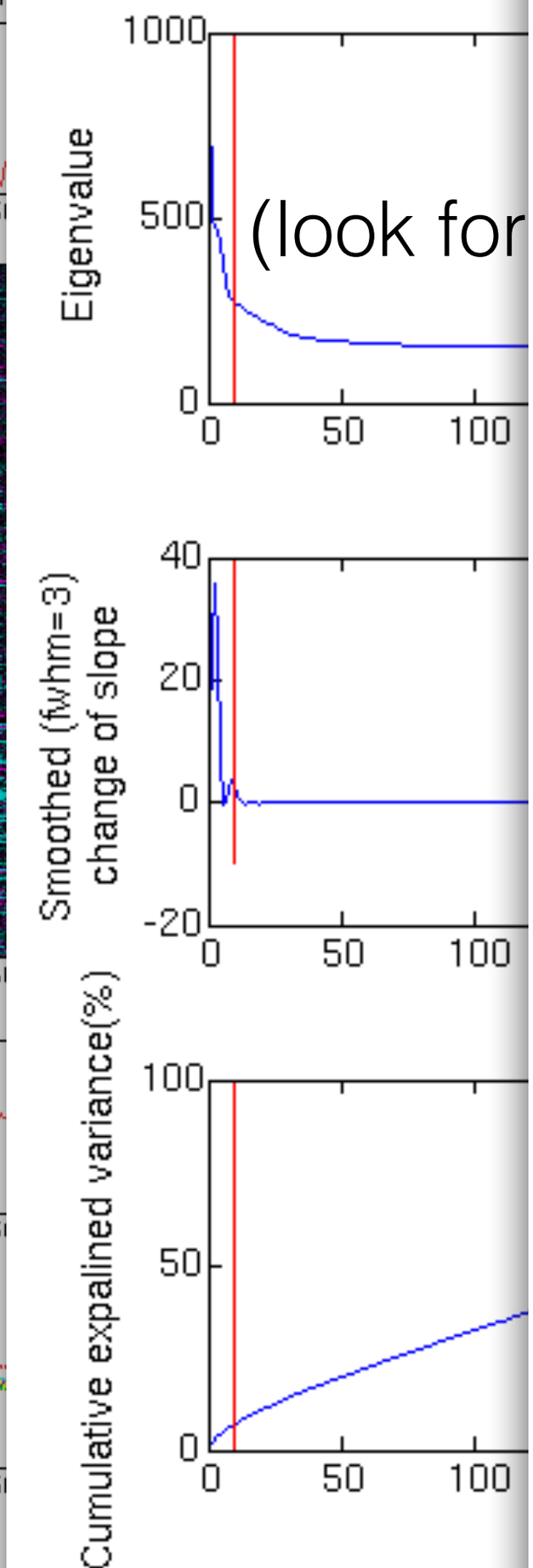
$$b_{gray} = S\hat{d} + P\hat{c} + G\hat{d} + C\hat{e}$$

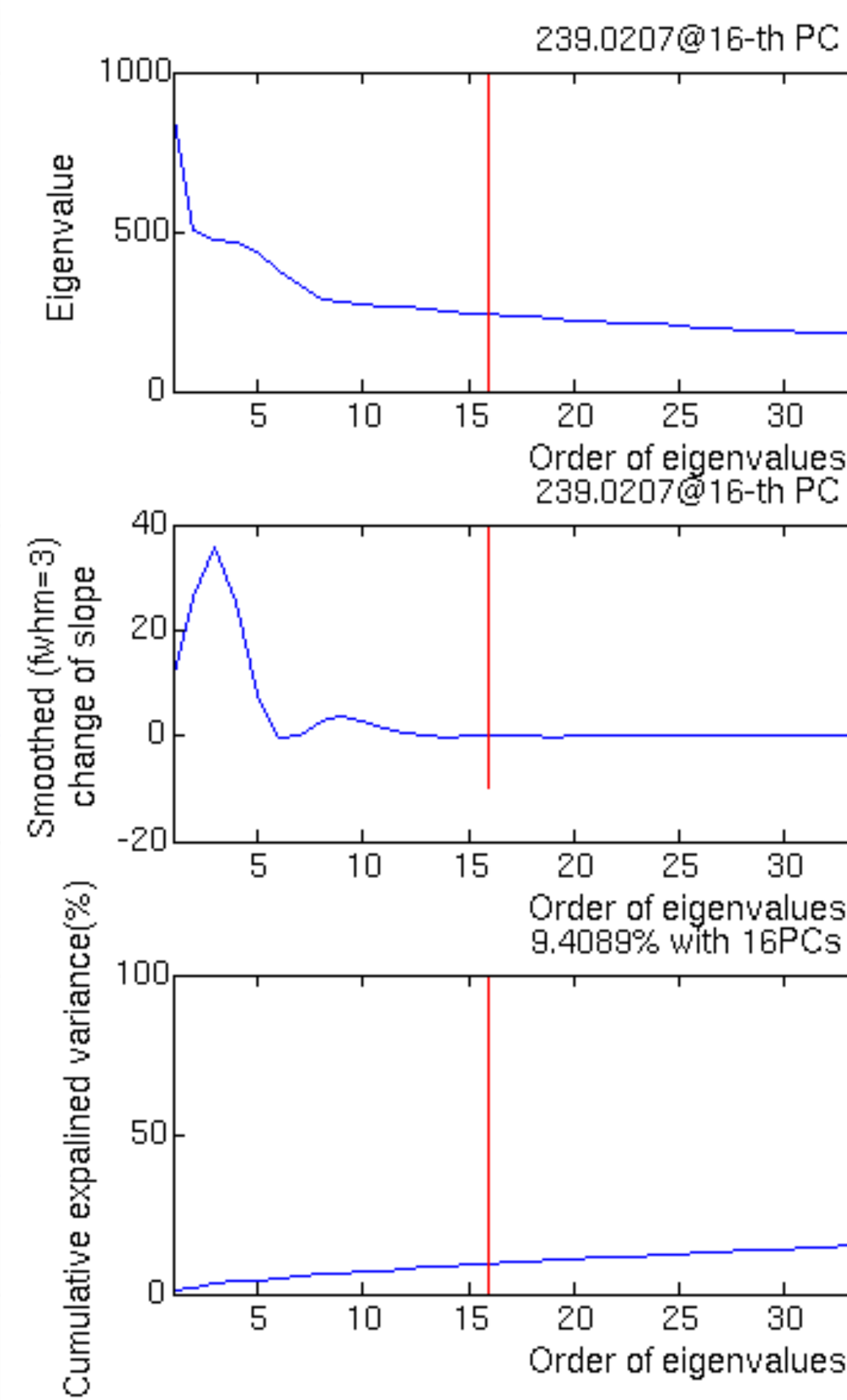
$$\text{residual} = b_{gray} - \hat{b}_{gray}$$

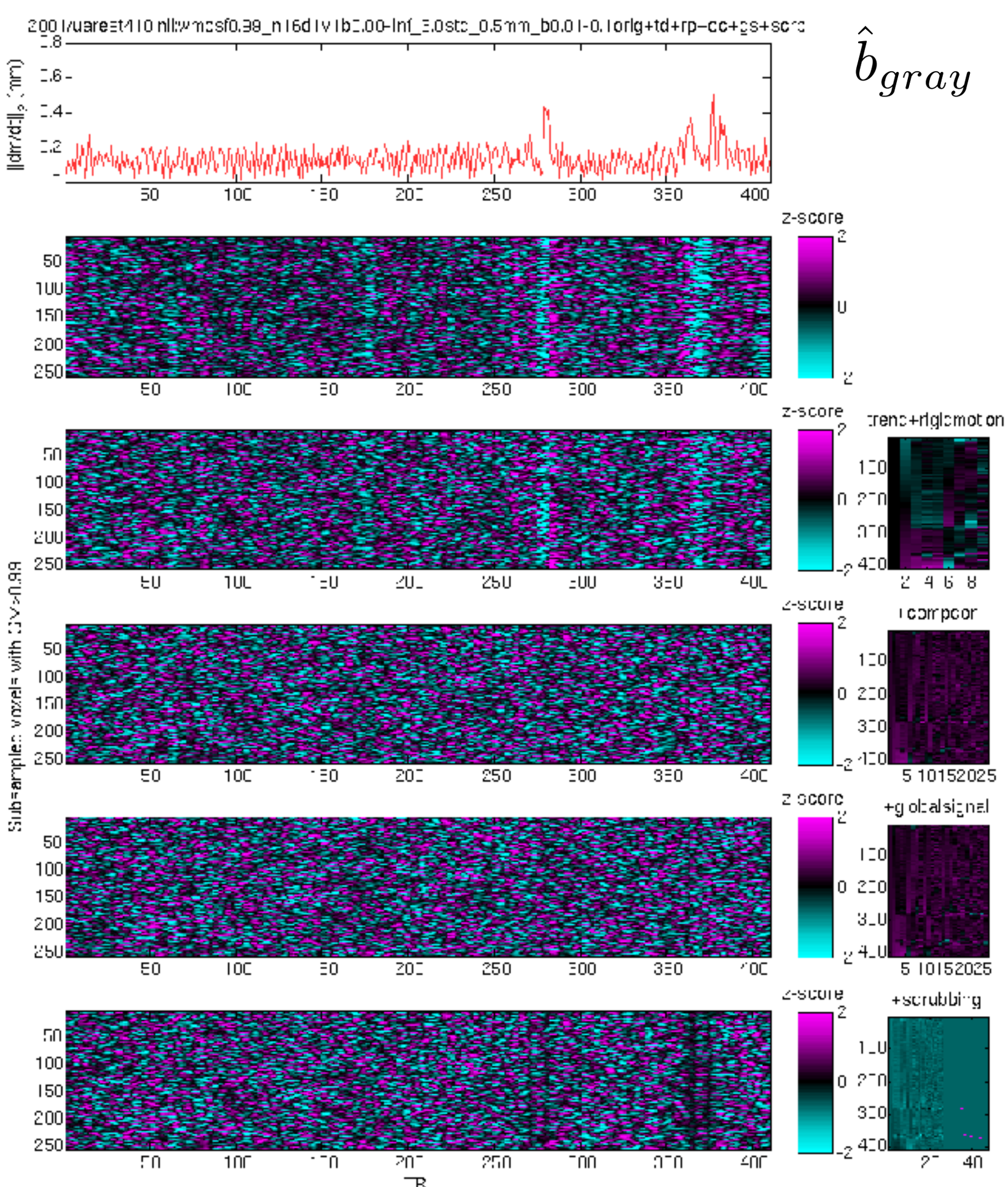
…really?

Visual inspection


/scr/vetiken2/APConn/rest12.417/2
‖dm/dt‖₂(mm)
x 10⁴
GM>0.95 voxels
mean GM>0.59
3PF=[0.00,Inf] Hz
Top 16 PCs
from wm+csf<0.55
TR


Eigenvalue
(look for
Smoothed (fwhm=3)
change of slope
Cumulative expalined variance(%)


239.0207@16-th PC
Eigenvalue
Order of eigenvalues
239.0207@16-th PC
Smoothed (fwhm=3)
change of slope
Order of eigenvalues
9.4089% with 16PCs
Cumulative expalined variance(%)
Order of eigenvalues



$\hat{b}_{gray}$

Head motion
(frame-wise)

Original

detrending (2)
+ rigidmotion (6+1)

+ CompCor
(16 PCs)

+ Global signal

+ Scrubbing
(21 outliers)

orig

+td+rp

+cc_th0.99_n16

+gs_0.99

+scrb_21

z-score

TR

GM>0.99 voxels in the slice

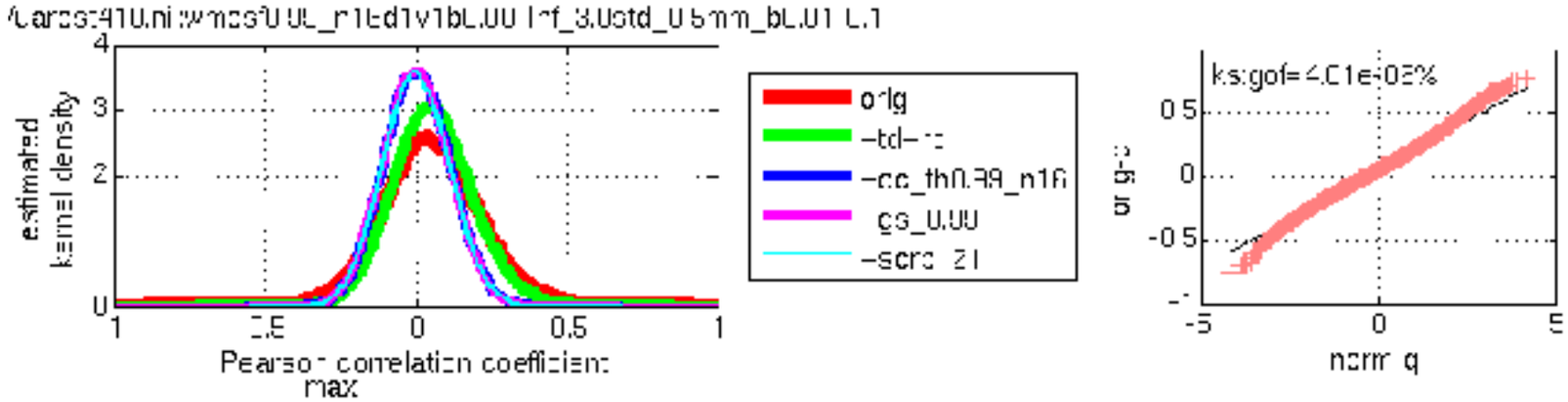
GM>0.99 voxels

Precuneous

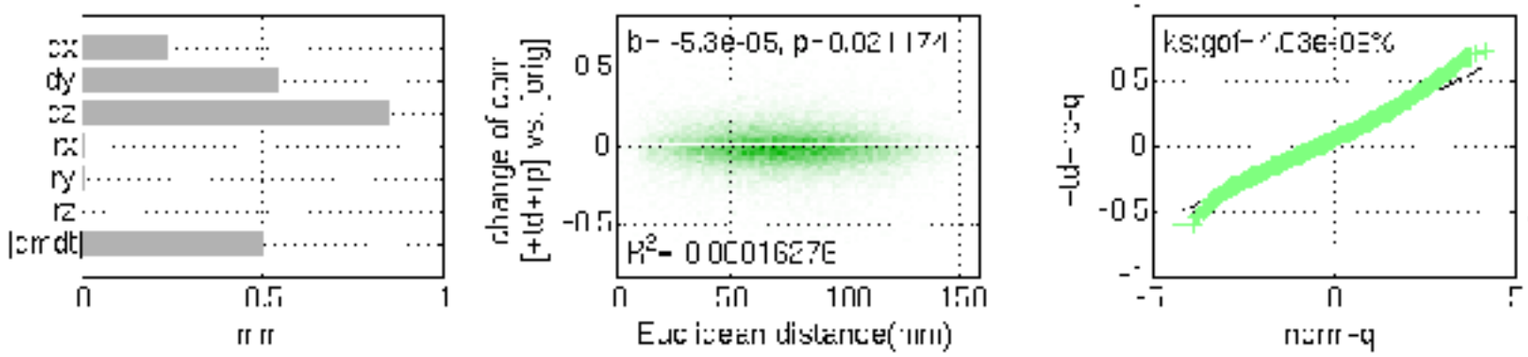
Central sulcus

Anterior cingulate gyrus

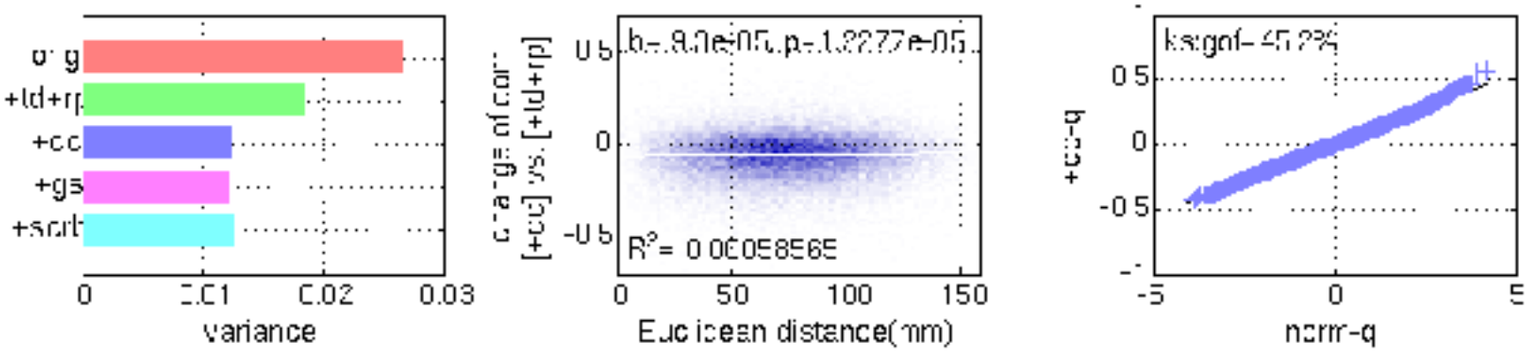
TR



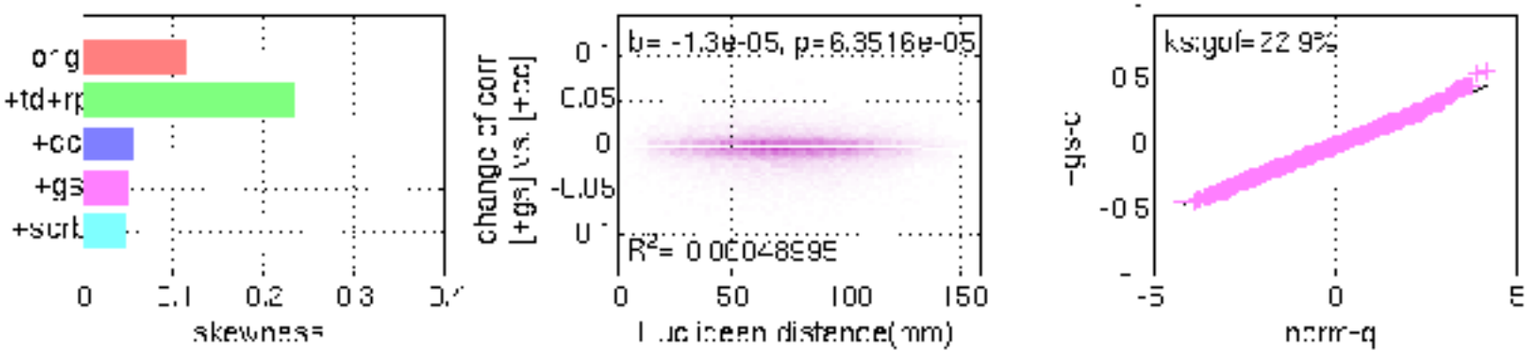
Original



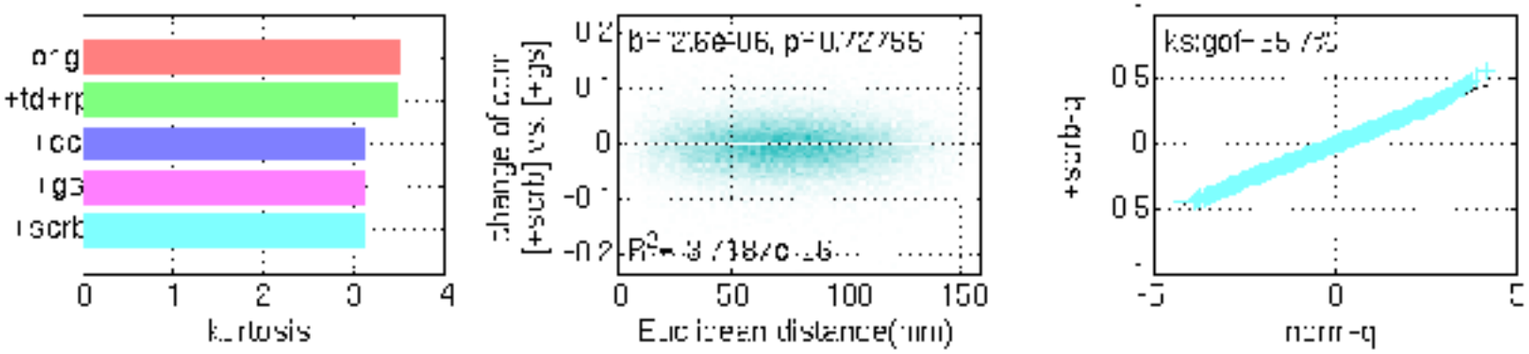
+ detrending (2)
+ rigidmotion (6+1)



+ CompCor
(16 PCs)



+ Global signal



+ Scrubbing
(21 outliers)

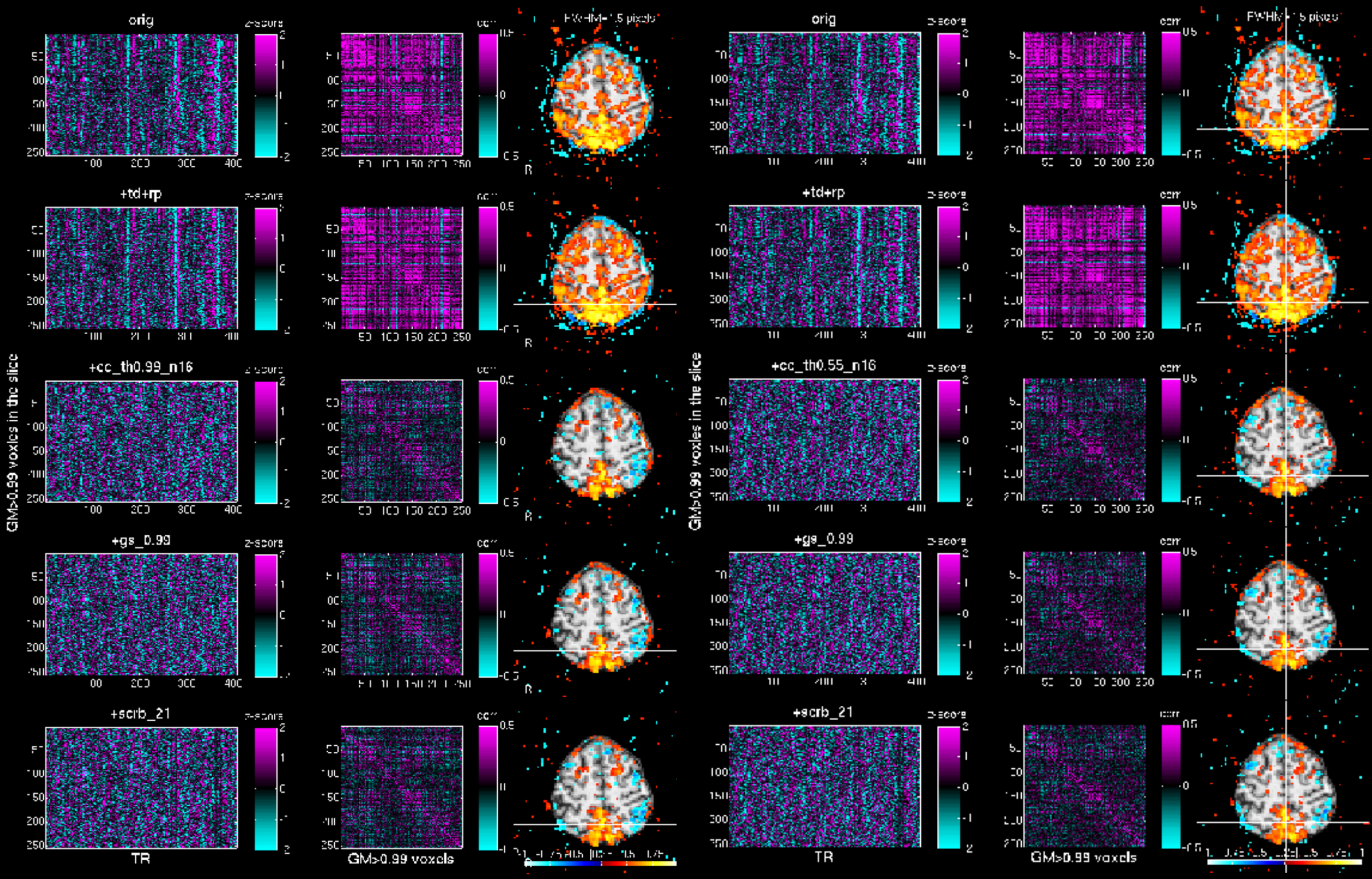
Question #3-1

- When extracting CompCor regressors from ‘WM’ and ‘CSF’ voxels, does WM/CSF threshold matter?

- Tissue probability > 0.99 vs. >0.55

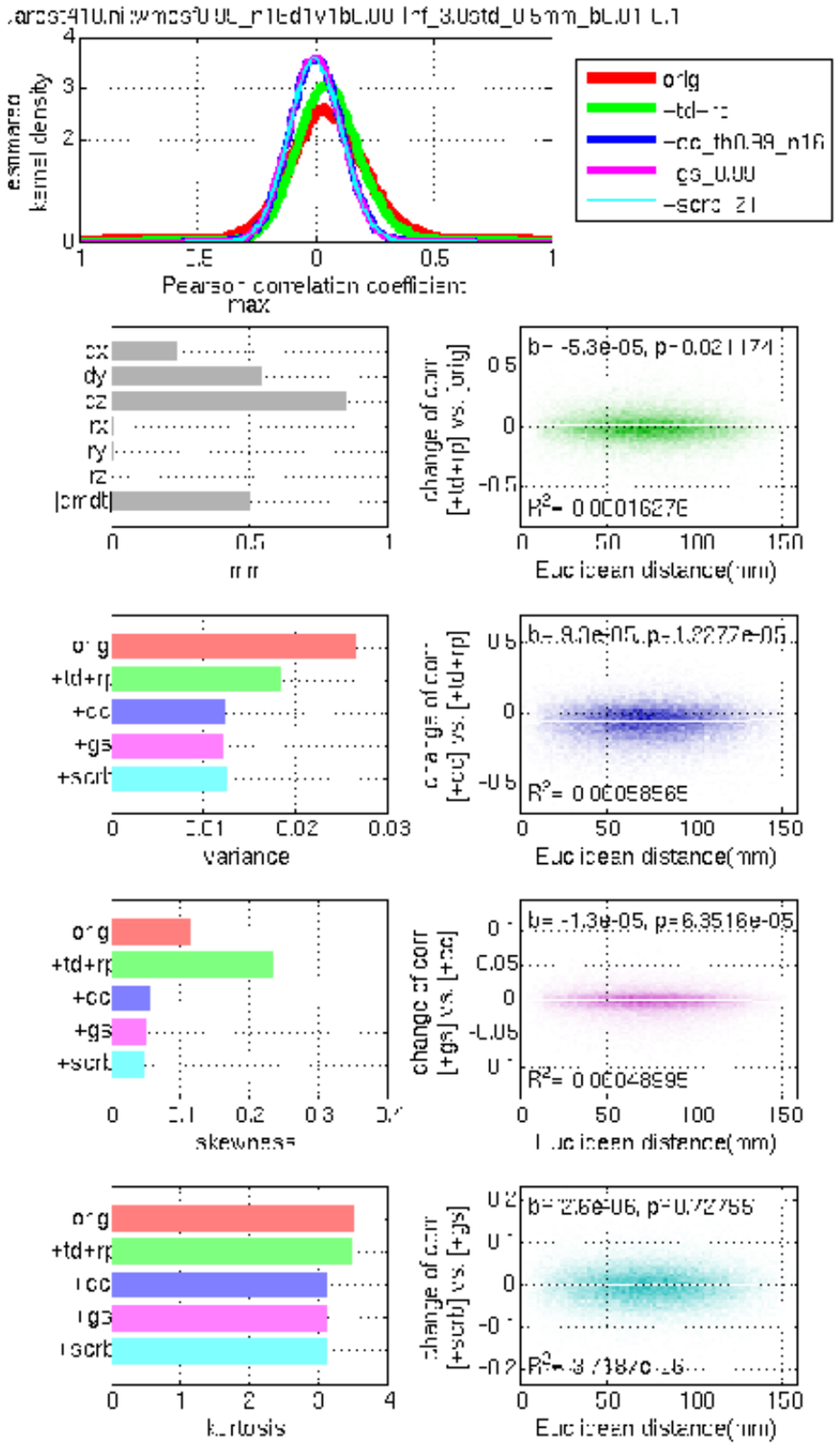
WM/CSF>0.99

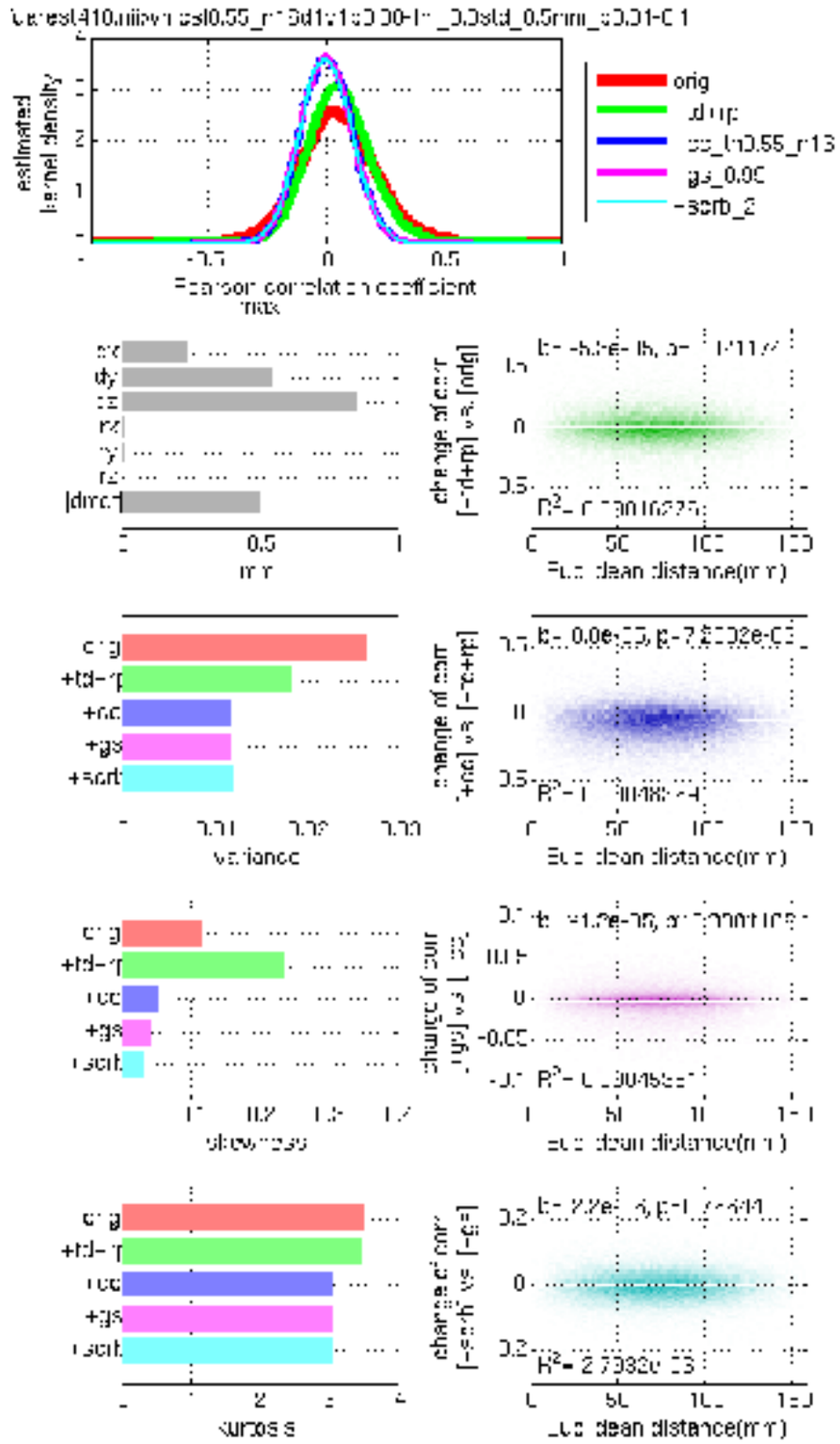
WM/CSF>0.55



WM/CSF>0.99

WM/CSF>0.55





Doesn't matter without *invasive* regressors (gs, scrubbing)

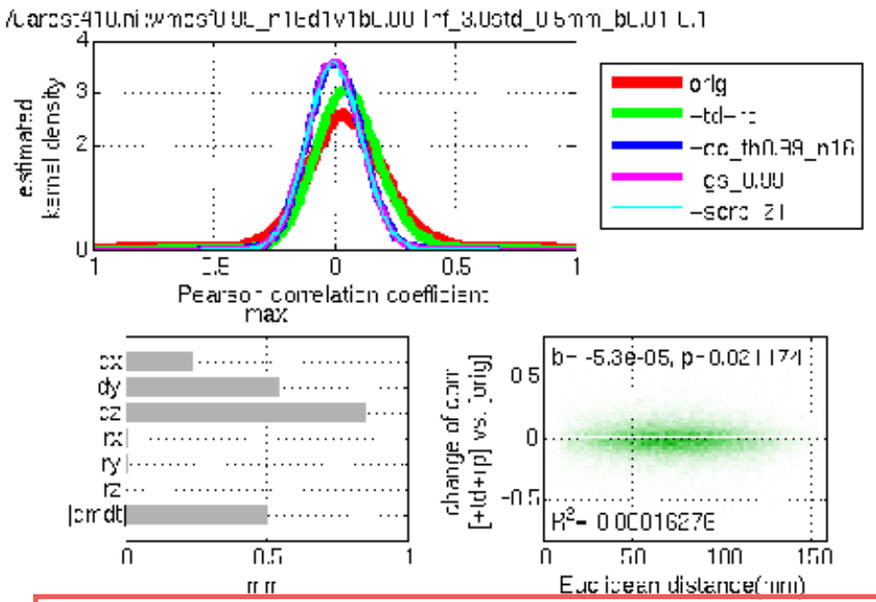
Question #3-2

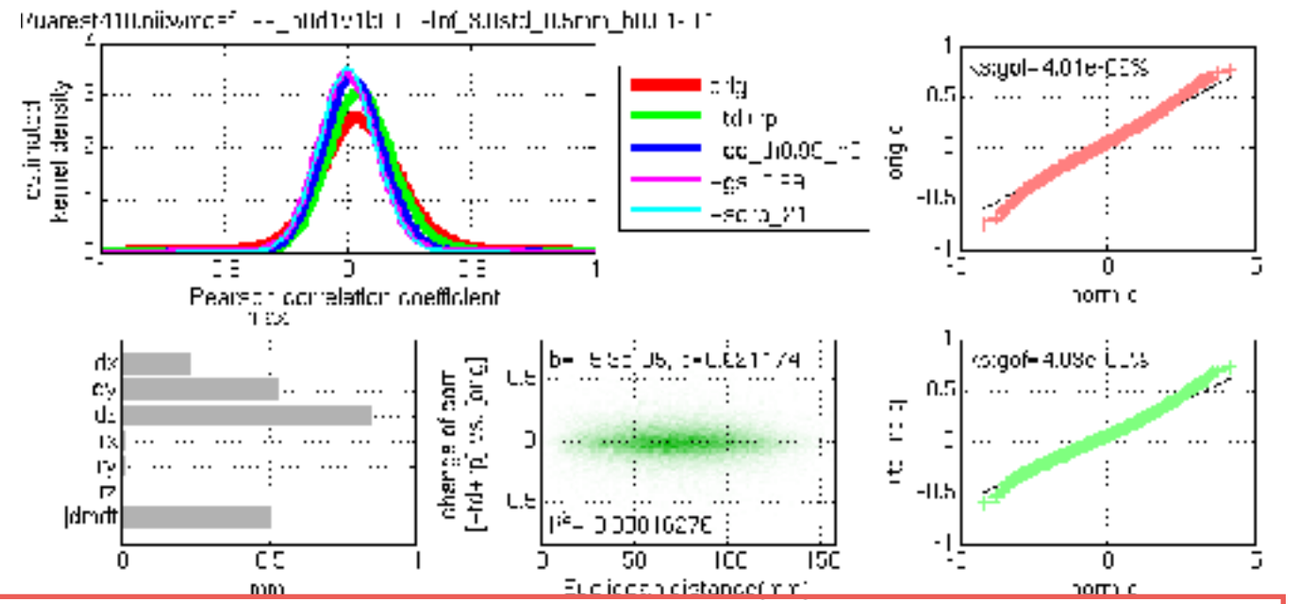
- When estimating non-neuronal ‘physiological noise’ from the WM/CSF voxels, averaging works as well as PCA?

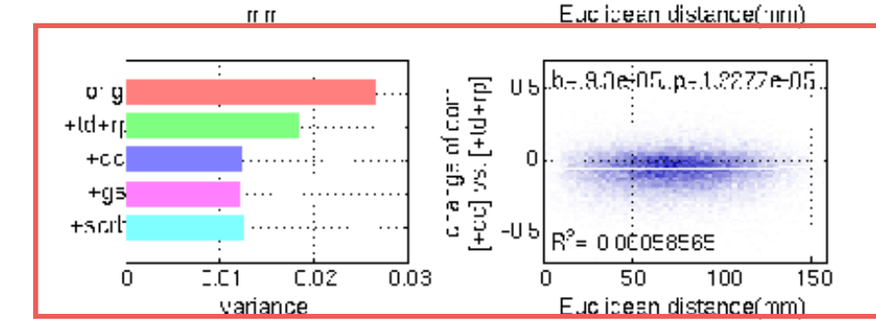
- Top 16 PCs vs. mean of WM/CSF

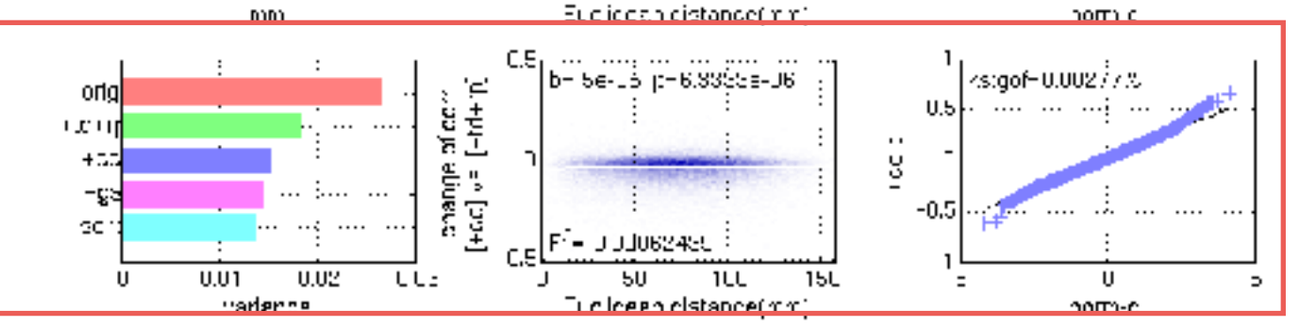
Top 16 PCs from WM/CSF

Mean WM/CSF





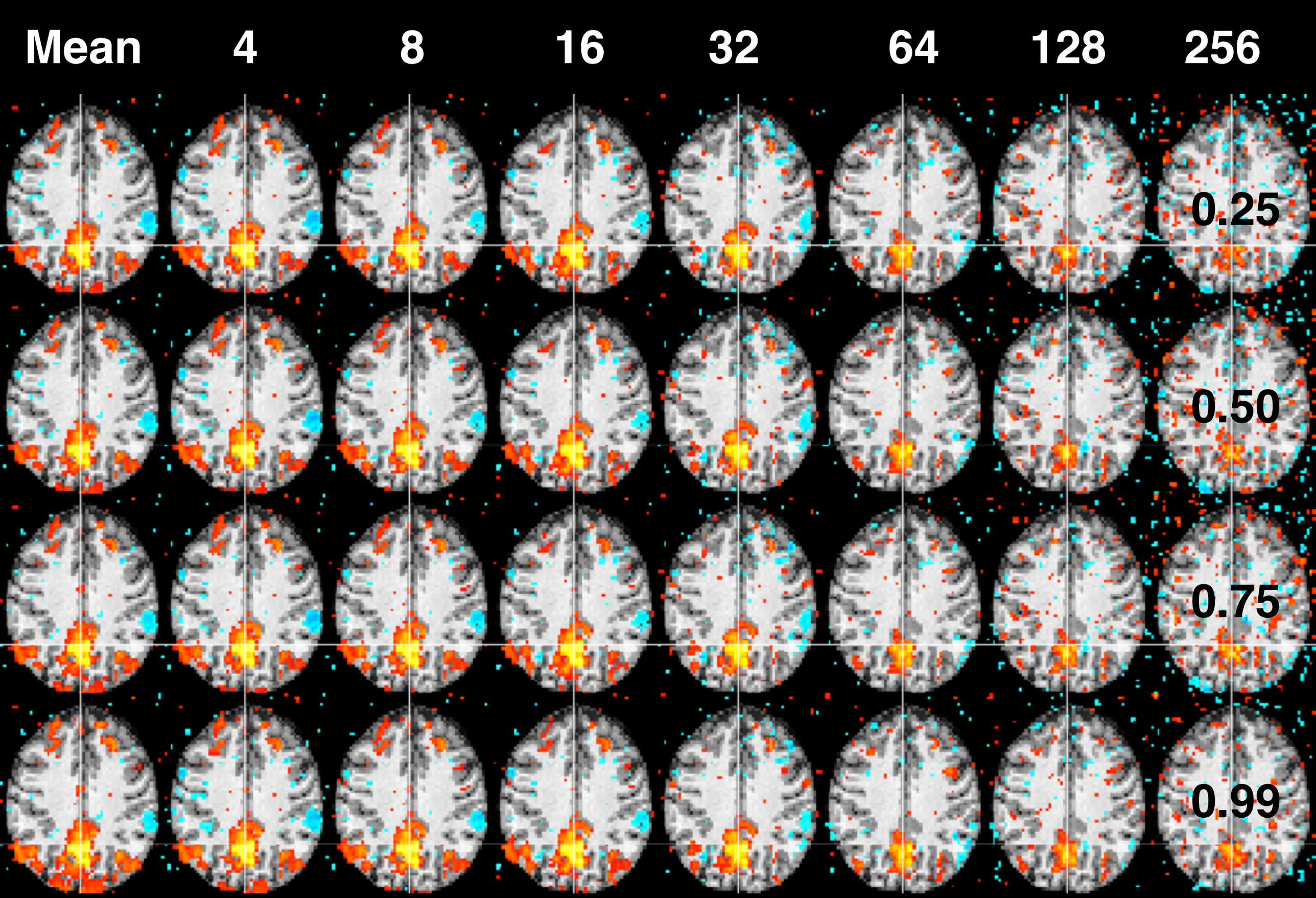




Both are better than just rigidmotion parameters

Question #3

- So which regressors and parameters should I use?
  - WM/CSF threshold
  - # of CompCor regressors
  - Global signal? Scrubbing?
  - Different combinations of regressors?


Mean
4
8
16
32
64
128
256
0.25
0.50
0.75
0.99
4e-5
0.006
0.042
0.388
0.652
0.653
0.408
0.270

FWHM=1.5 pixels

FWHM=1.5 pixels

FWHM=1.5 pixels

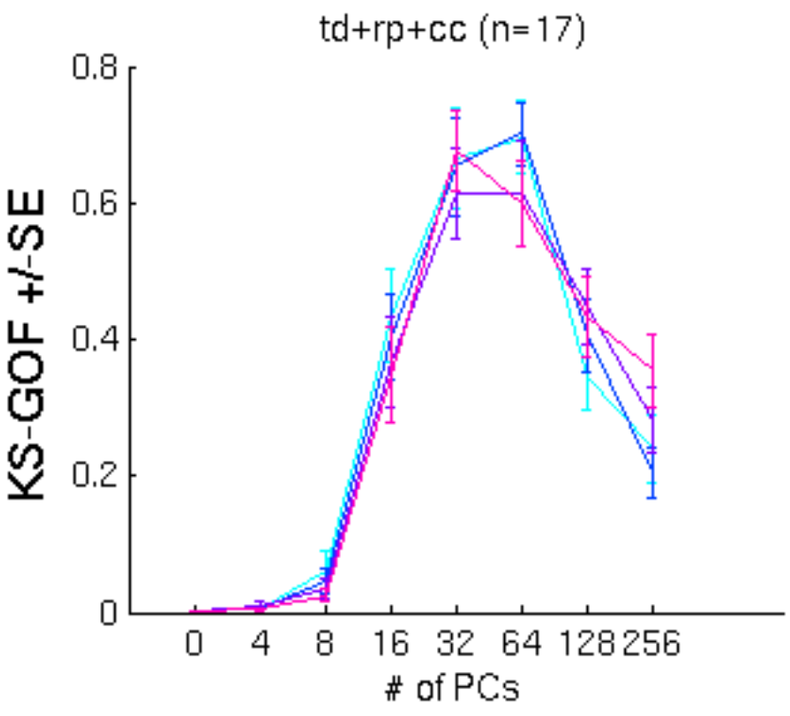
GM>0.99 voxels

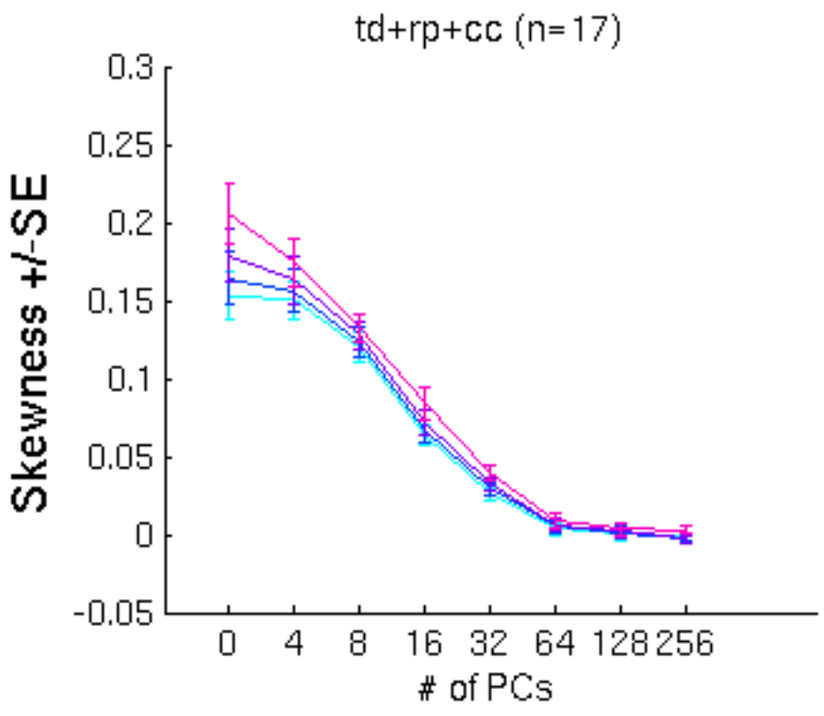
GM>0.99 voxels

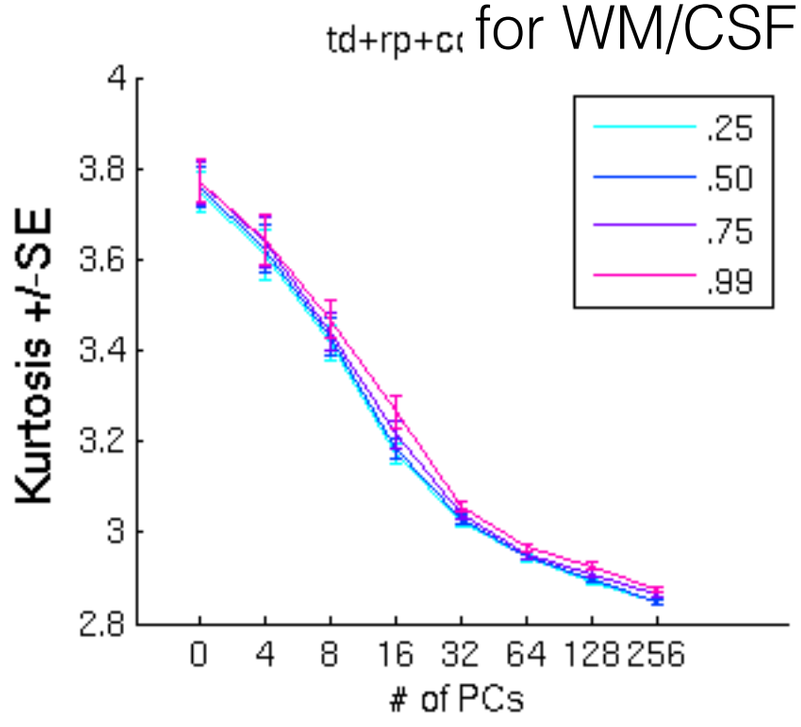
GM>0.99 voxels

b = 1 + trend + motion + CompCor (n=17)

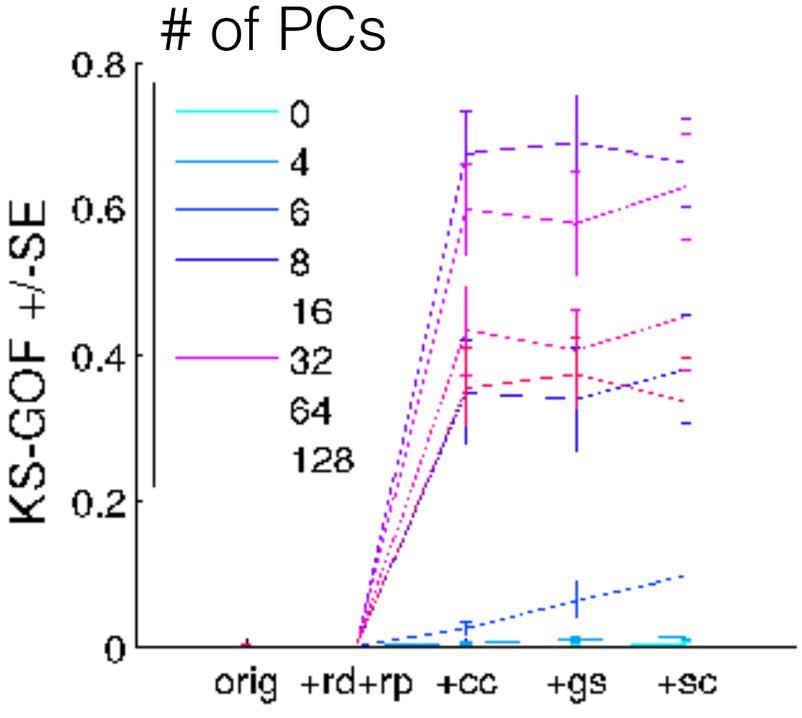
Threshold for WM/CSF

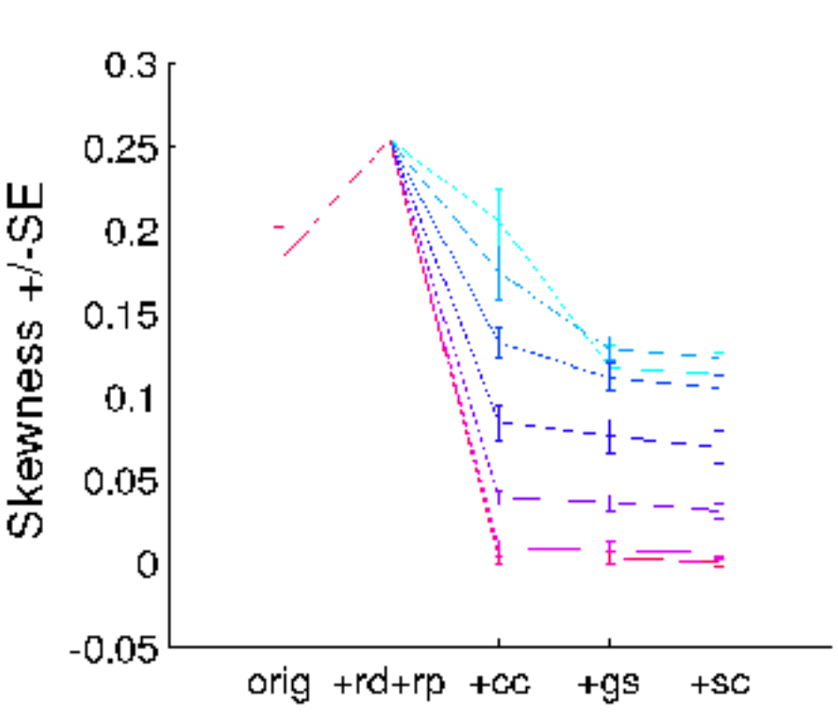


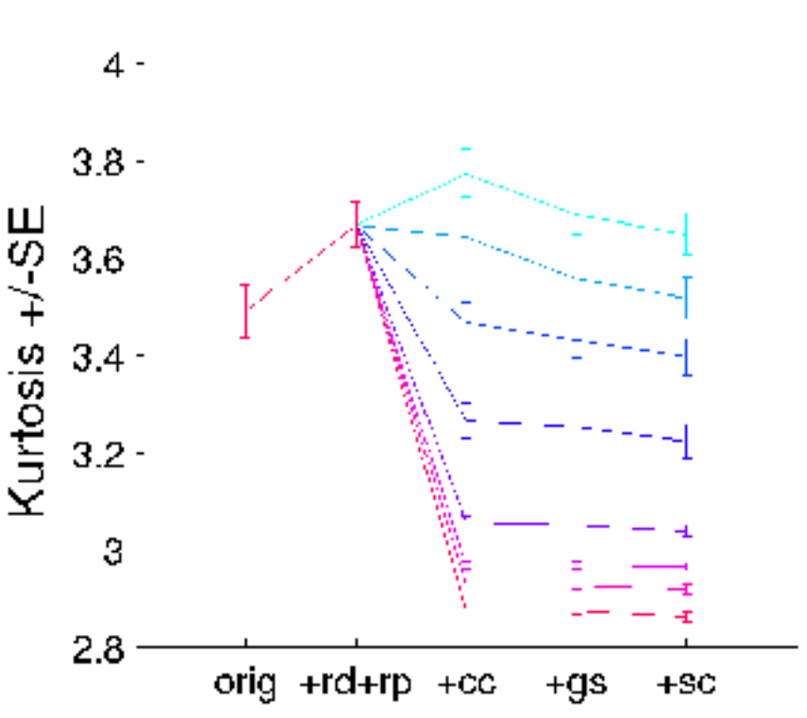




WM/CSF>0.99 (n=17)







Conclusion

- Head motion spuriously heightens correlation between BOLD timeseries (directly affects topological measures such as degree centrality).

- CompCor regressors, or at least the mean, from WM/CSF voxels normalize correlation distribution.

- Denoising regressors should be tailored to the nature of the data on hands (e.g., a children study may benefit from scrubbing).

And further discussion!