
Artefact Removal (Physiological)

Rasmus M. Birn, Ph.D.



University of Wisconsin
SCHOOL OF MEDICINE
AND PUBLIC HEALTH

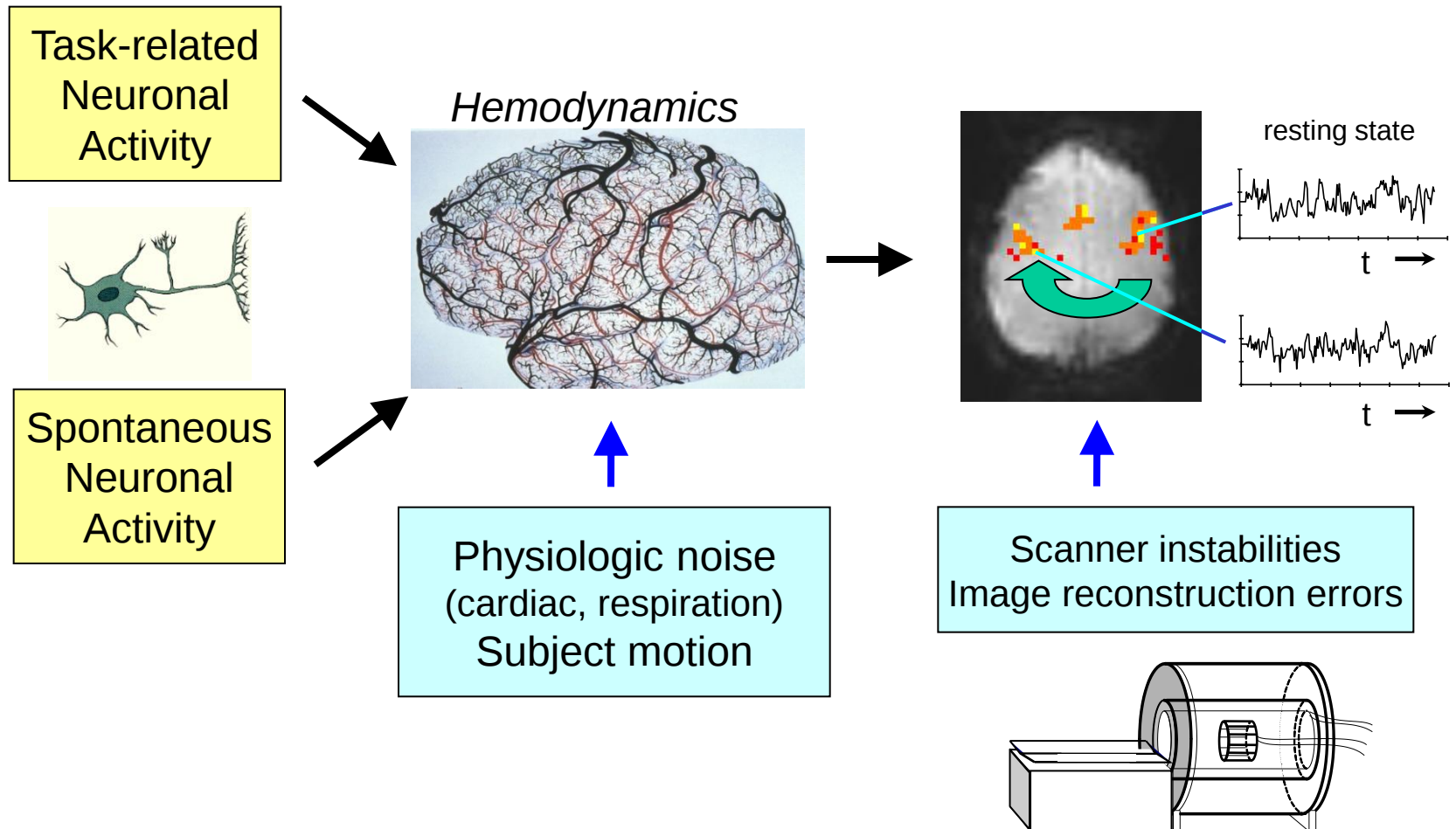


Overview

- The Problem
 - Cardiac Fluctuations
 - Respiration
- Solutions
- Issues to consider
 - How can correction be improved?
 - What about global signal regression?
 - Should we correct for physiological noise?

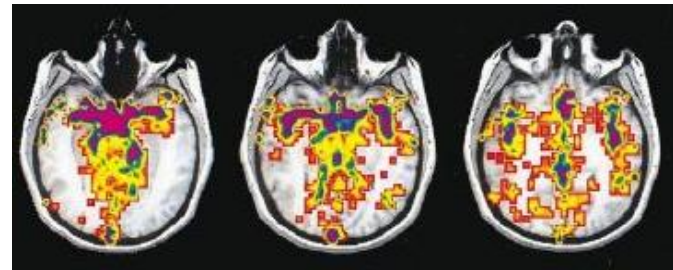
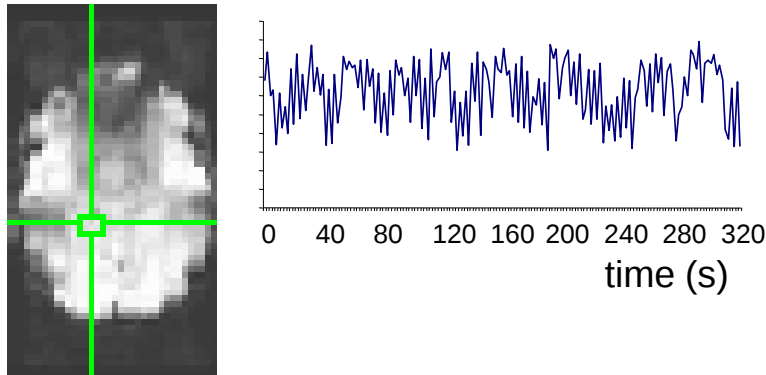


Functional MRI



Physiological noise

Cardiac



M.S. Dagli et al., NeuroImage 9, 1999

Respiration

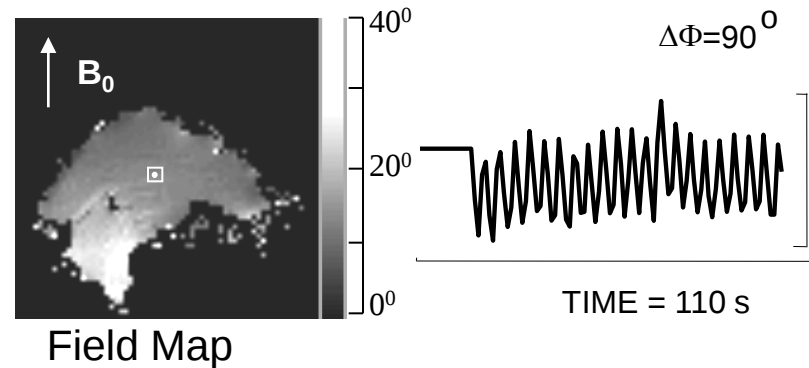
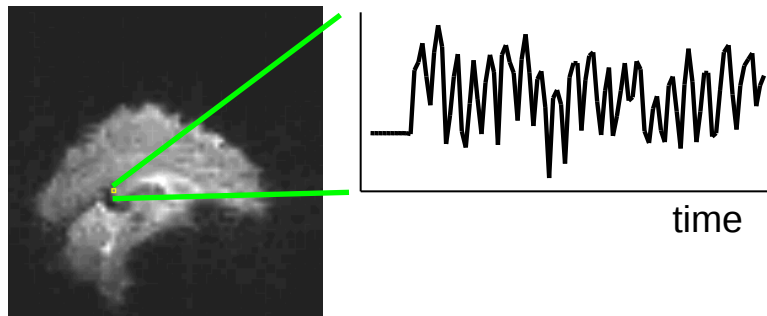


Figure courtesy of J. Bodurka



Physiological Noise

The brain is not a rigid body

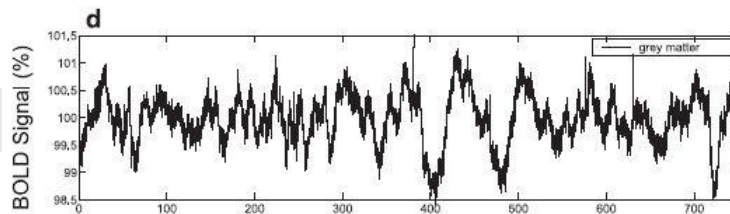


B.P. Poncelet et al., Radiology, 185:645-651, 1992.

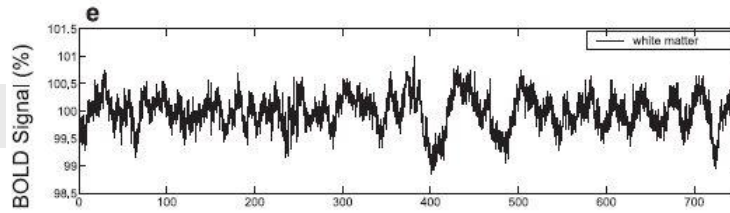
Physio. fluctuations can occur at low frequencies

Variations in breathing during rest $\rightarrow \Delta BOLD$ signal

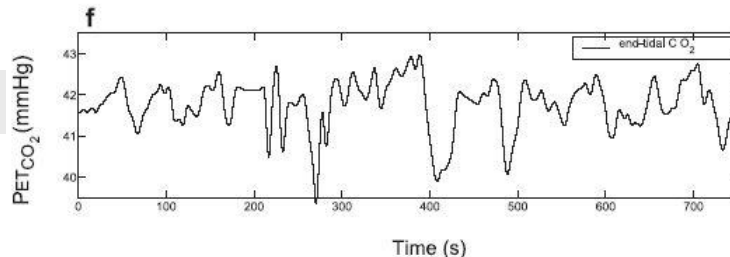
BOLD (GM)



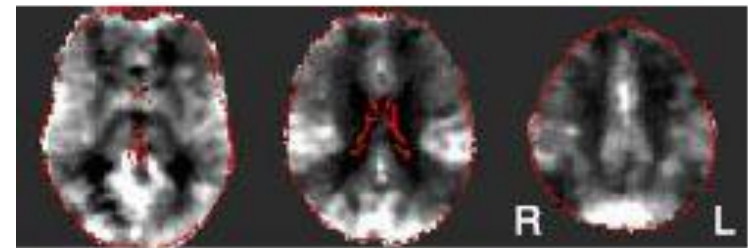
BOLD (WM)



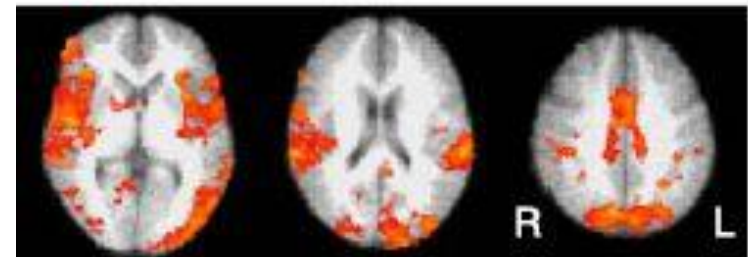
$P_{ET}CO_2$



$\Delta P_{ET}CO_2$ correlated w/ $\Delta BOLD$



$\% \Delta S_{BOLD} / \text{mmHg}$
-0.05 0.25

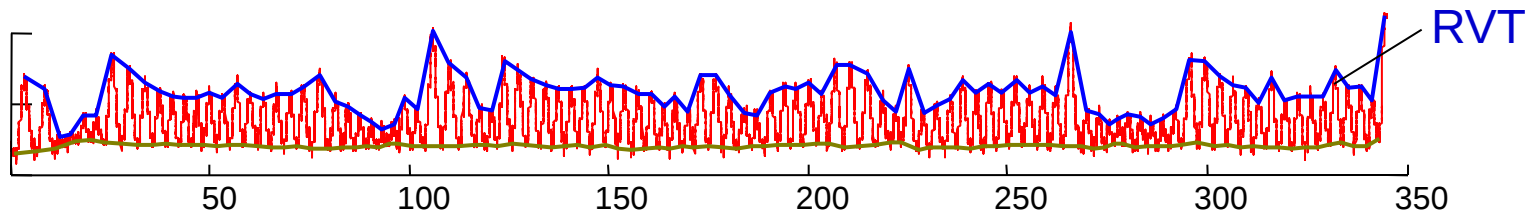


Z score
2.0 3.7

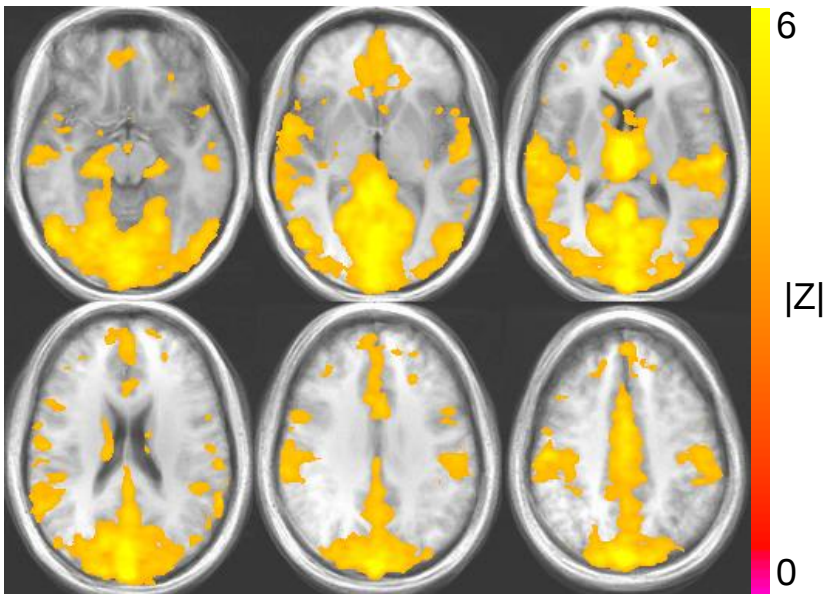
R.G. Wise et al., NeuroImage 21, 2004



Resting fluctuations in respiration



RVT-related changes

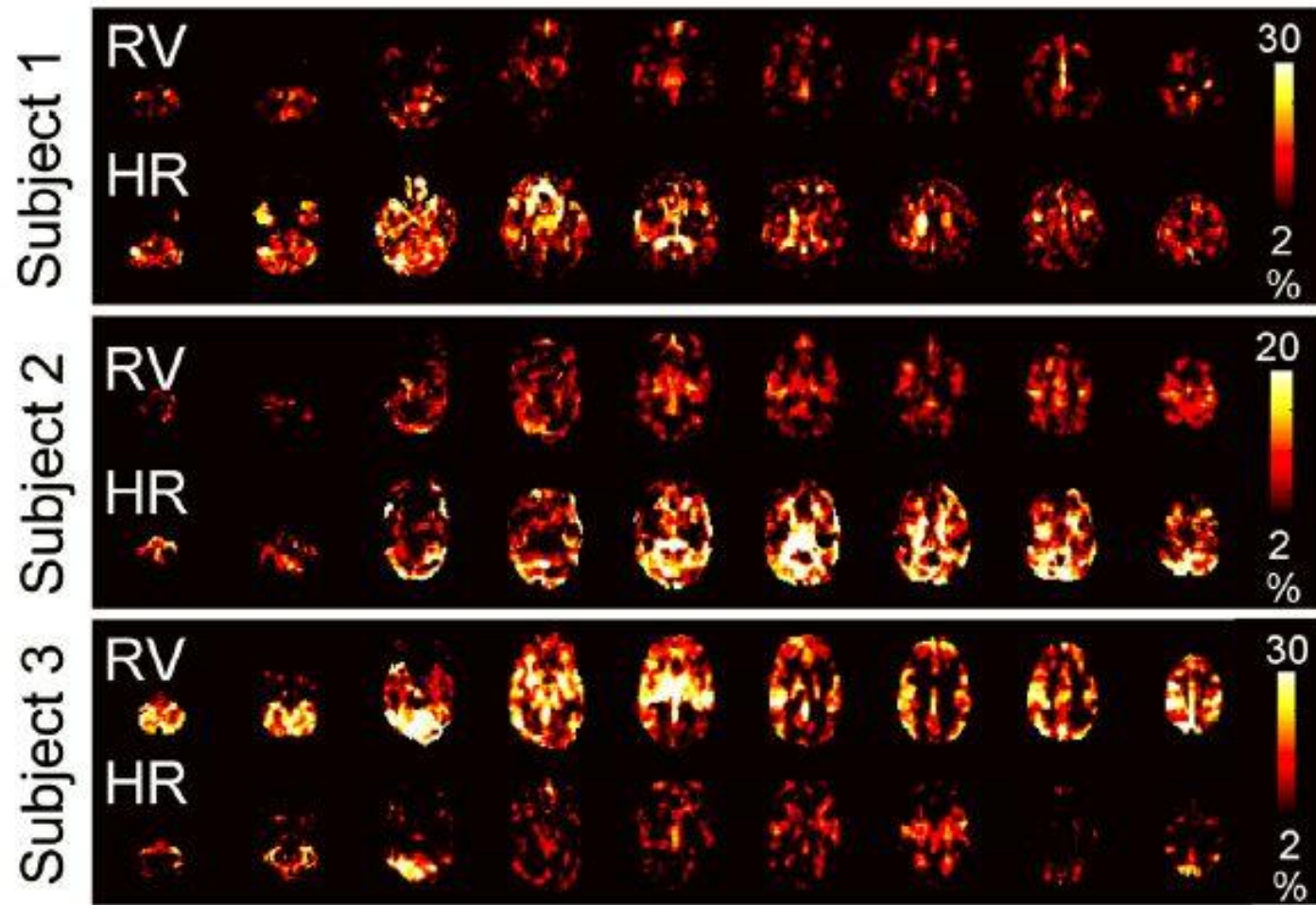


*RVT = Respiration
Volume per Time*

group (n=11)



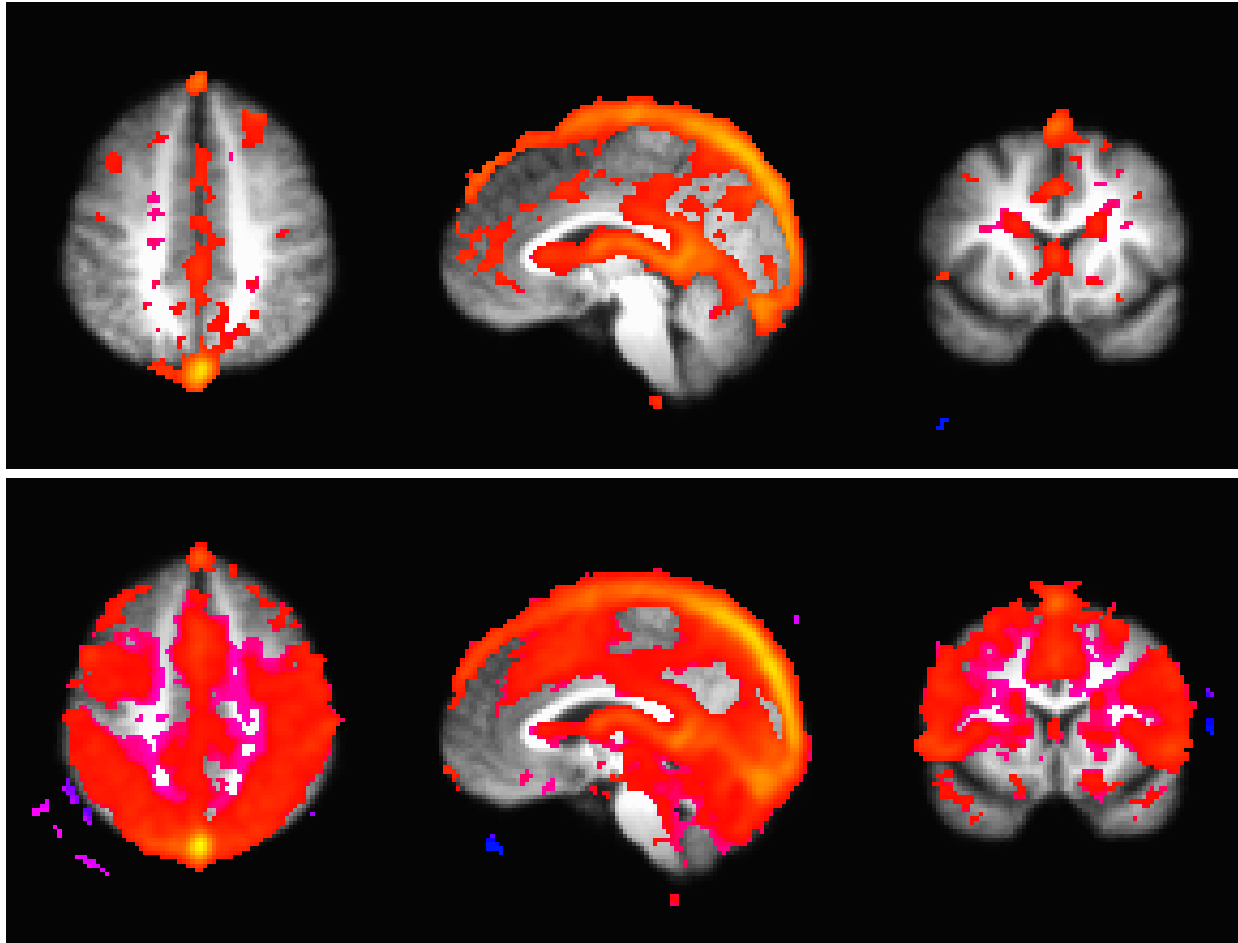
Effects of Heart Rate



C. Chang et al., Neuroimage 2009



Heart Rate



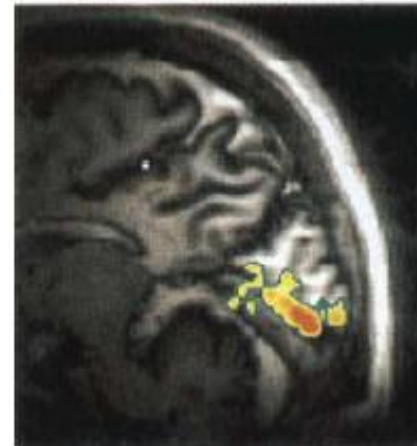
Birn et al. (unpublished)



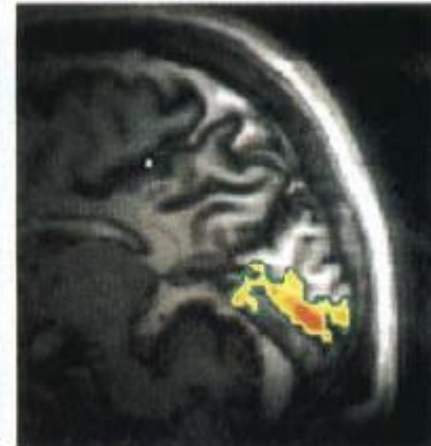
Impact of Physiological Noise

...on fMRI

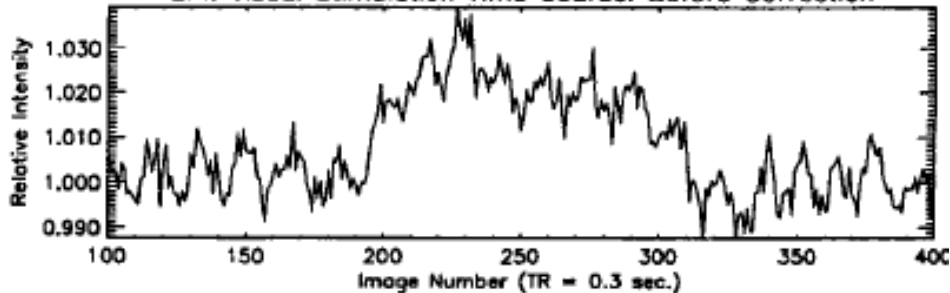
Before correction



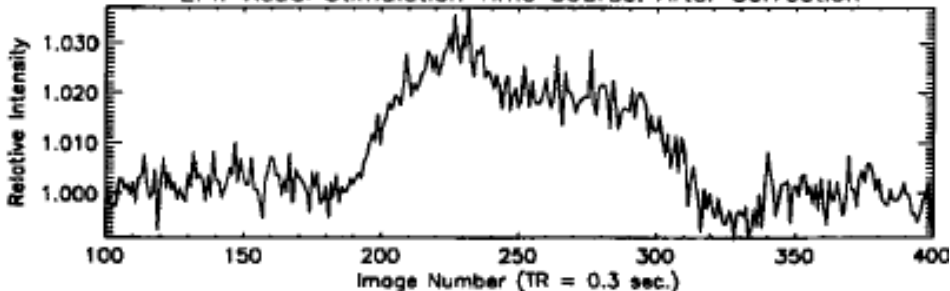
After correction



EPI: Visual Stimulation Time Course: Before Correction



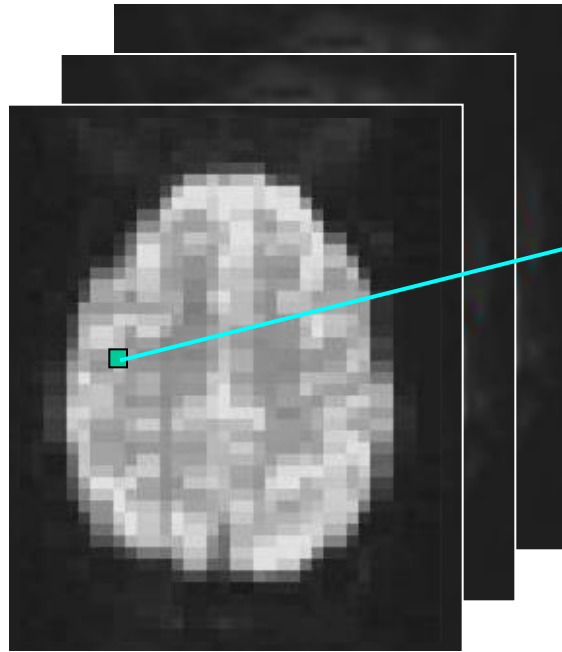
EPI: Visual Stimulation Time Course: After Correction



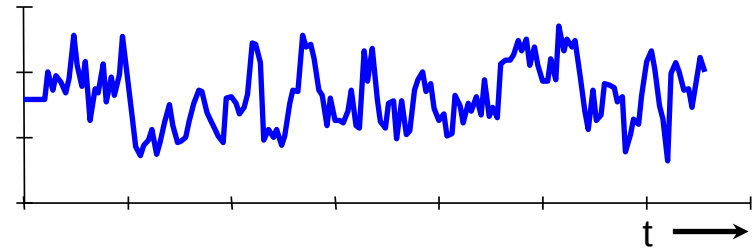
*X. Hu et al.,
Magn. Res. Med. 1995*



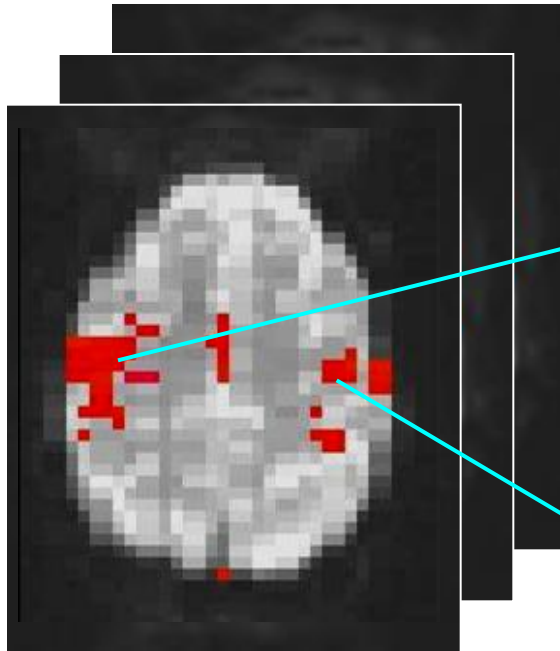
Resting-state Functional Connectivity



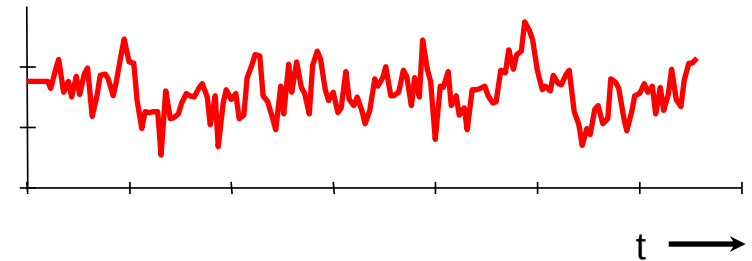
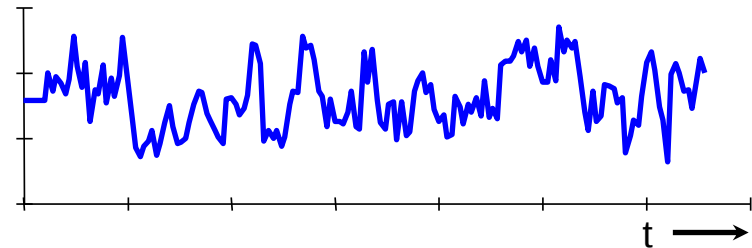
resting state



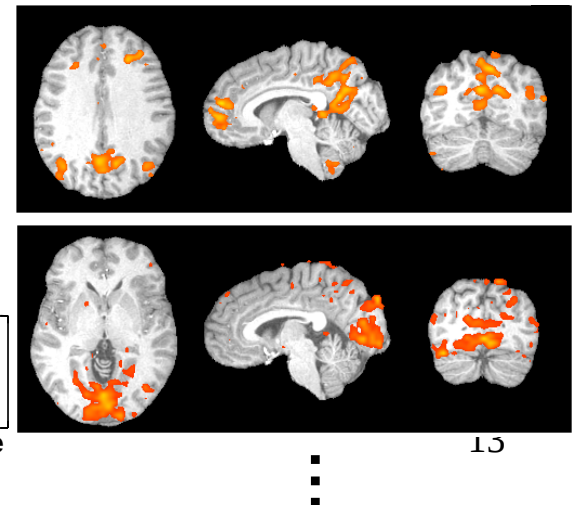
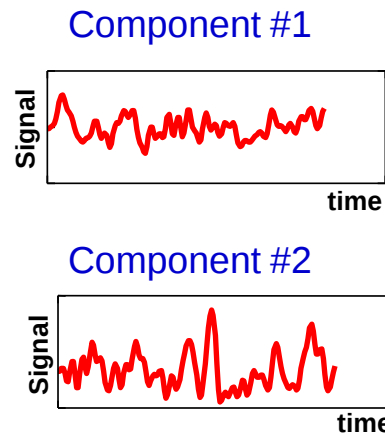
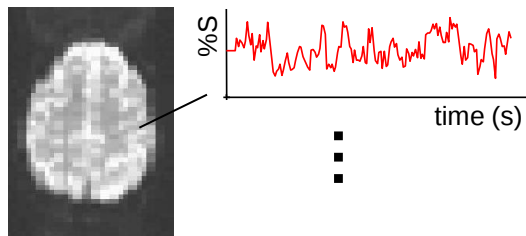
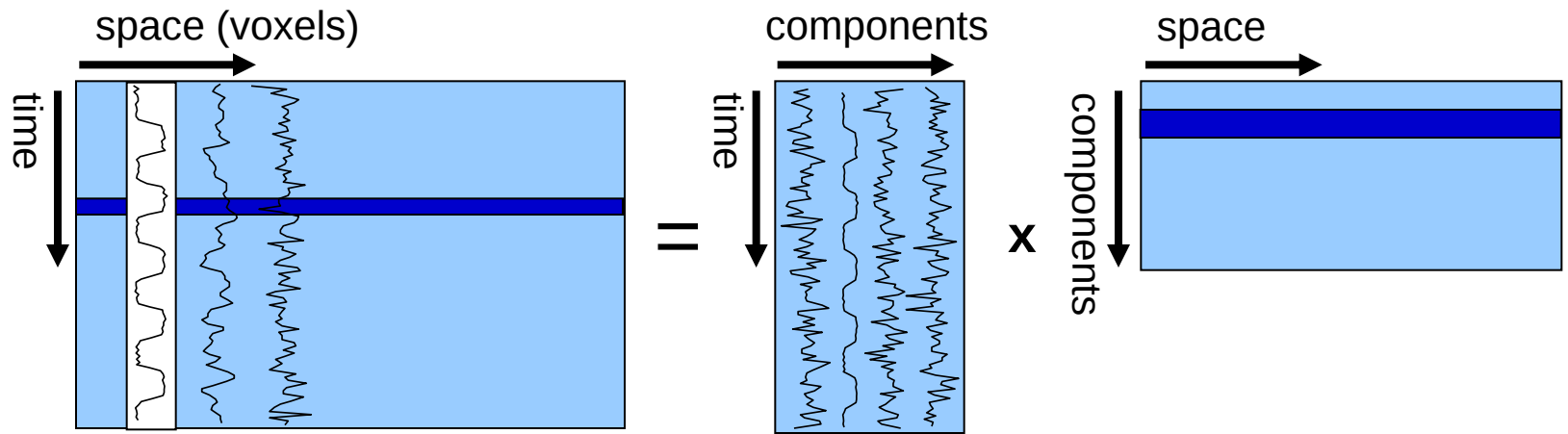
Resting-state Functional Connectivity



resting state



Independent Component Analysis

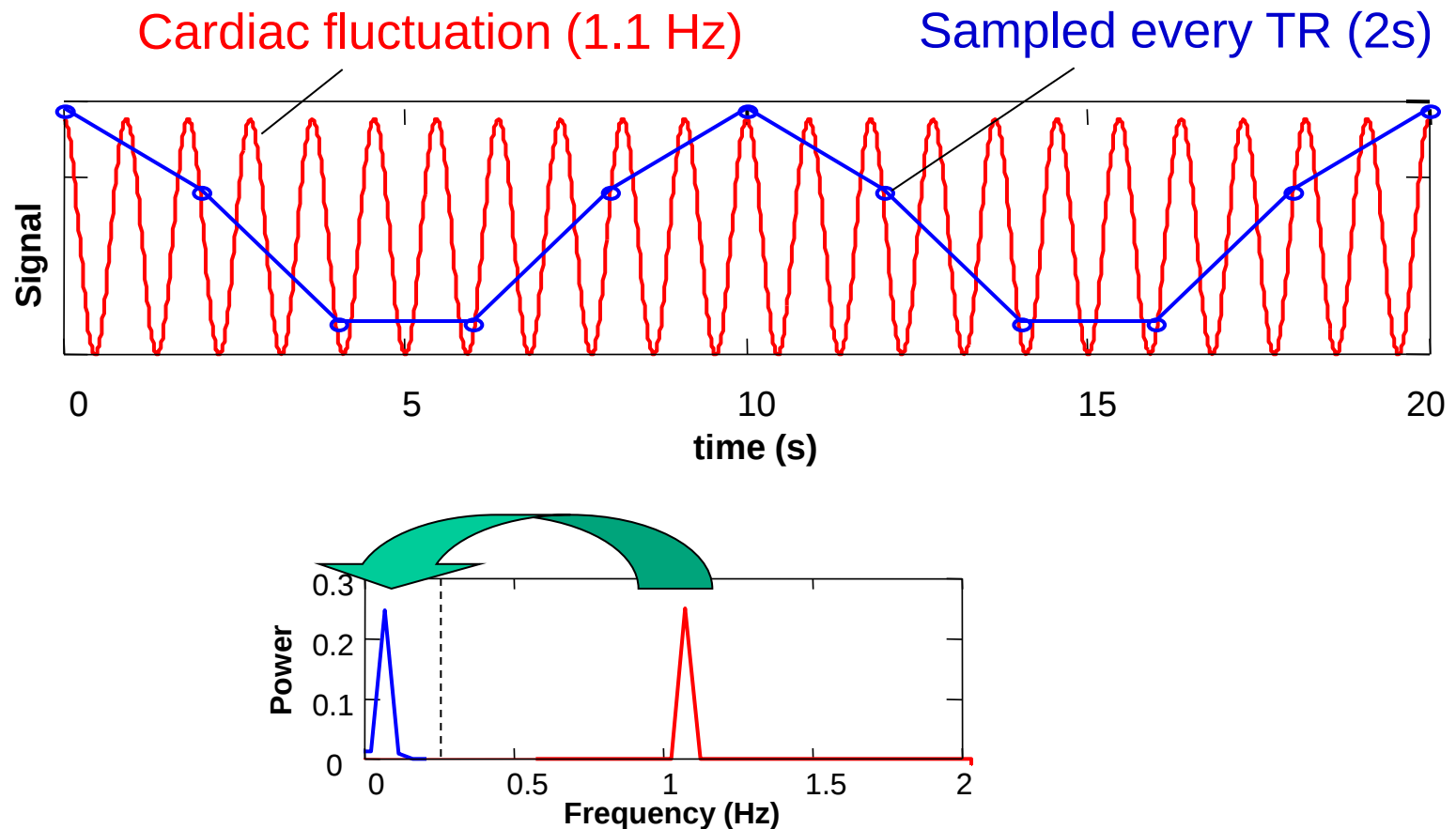


Tools to correct for physiological noise

- Filtering - Works only if TR is short enough ($< 400\text{ms}$)
- IMPACT (*Chuang et al., 2001*) – if TR short enough
- Retrospective correction (k-space) (*X. Hu et al., 1995*)
- RETROICOR (*Glover et al., 2000*)
- CORSICA (*V. Pelbarg, et al., 2007*)
- PESTICA (*E.B. Beall, et al., 2007*)
- RVTcor (*R.M. Birn, et al., 2006*)
- RVHRcor (*C. Chang, et al., 2009*)
- ANATICOR (*H-J. Jo, et al.,*)
- APPLECOR, PEARCOR (*M Marx, et al., 2013*)
- PSTCor (*J.S. Anderson, et al., 2011*)
- CompCor (*Y. Behzadi, et al., 2007*)
- FIX (*L. Griffanti, et al., 2014*)

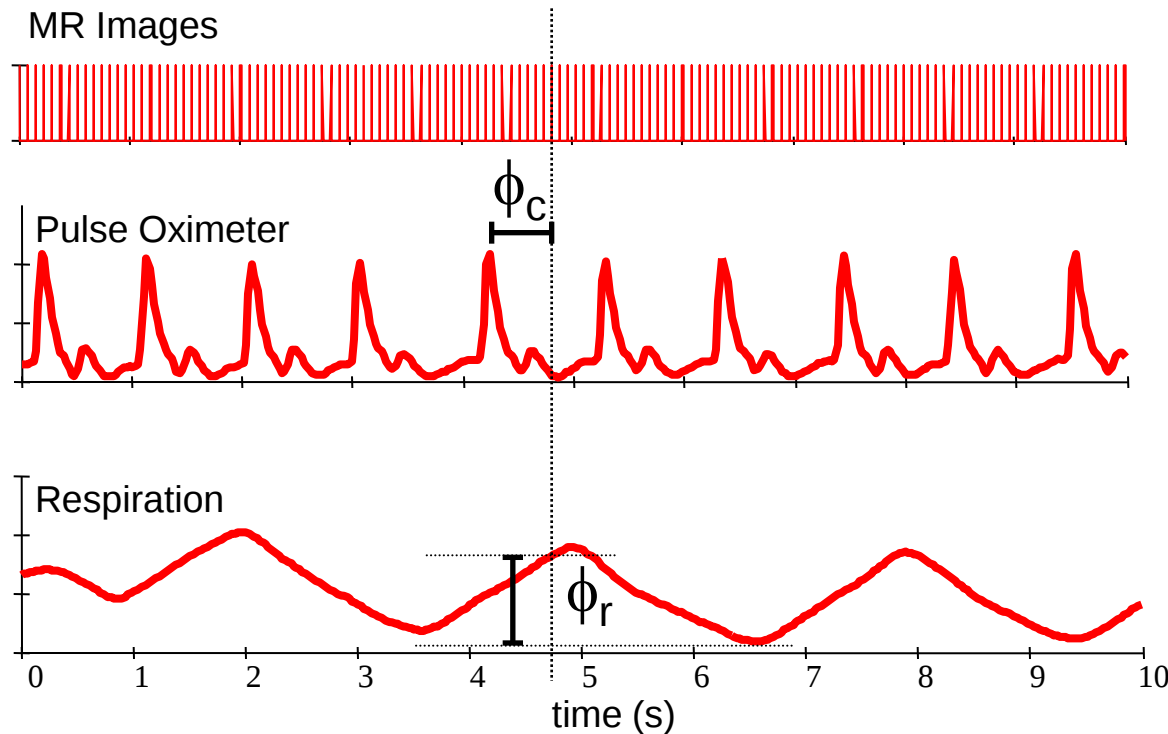
Can filtering ($<0.1\text{Hz}$) reduce cardiac noise?

- Not always: **Aliasing**



Correction of physiological noise

RETROICOR (G. Glover et al., *Magn. Reson. Med.* 44, 2000.)

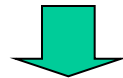
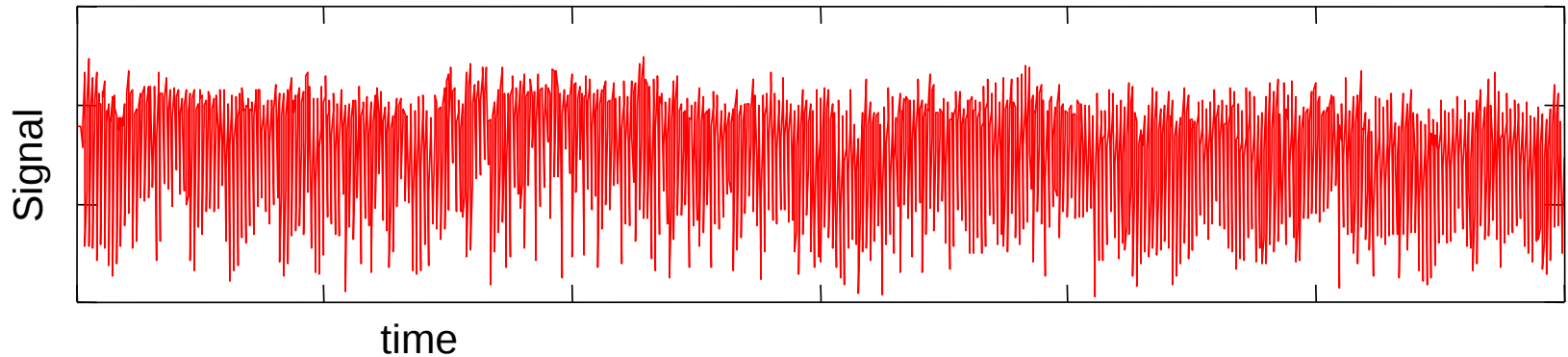


*Additional
Regressors:*

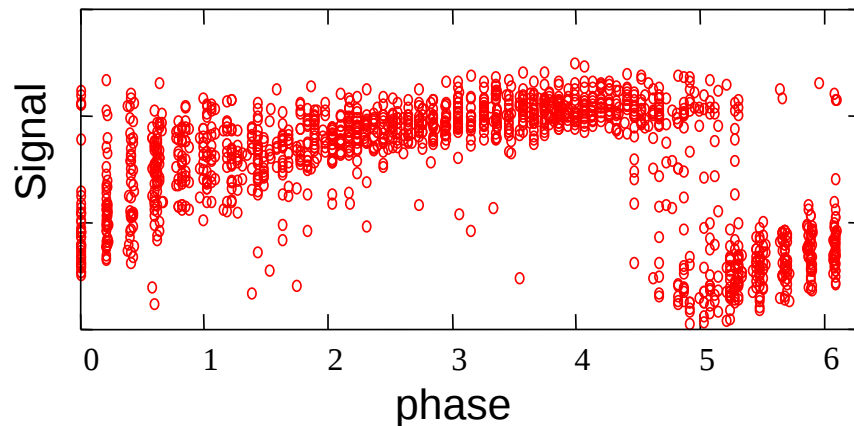
$$\left\{ \begin{array}{l} \sin(\phi_c) \\ \cos(\phi_c) \\ \sin(2\phi_c) \\ \cos(2\phi_c) \\ \sin(\phi_r) \\ \cos(\phi_r) \\ \sin(2\phi_r) \\ \cos(2\phi_r) \end{array} \right\}$$



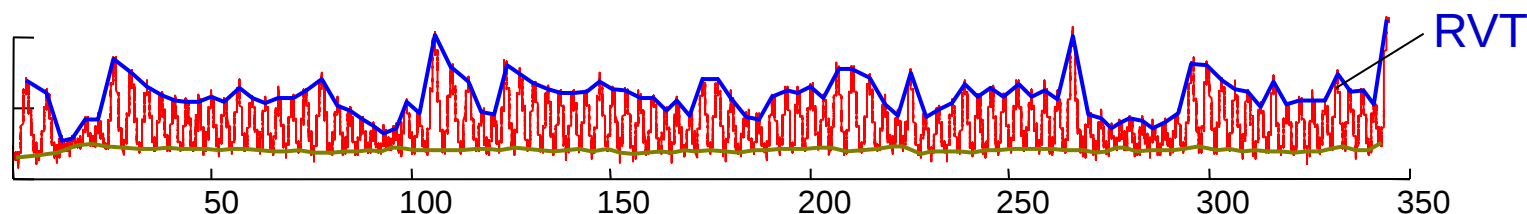
Correction of physiological noise



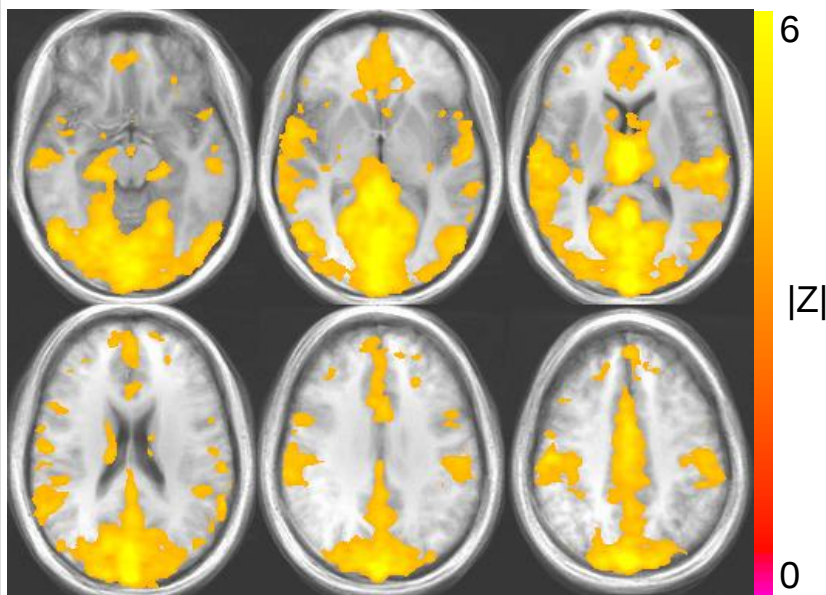
Reshuffle the data based on its cardiac or respiration phase



Resting fluctuations in respiration

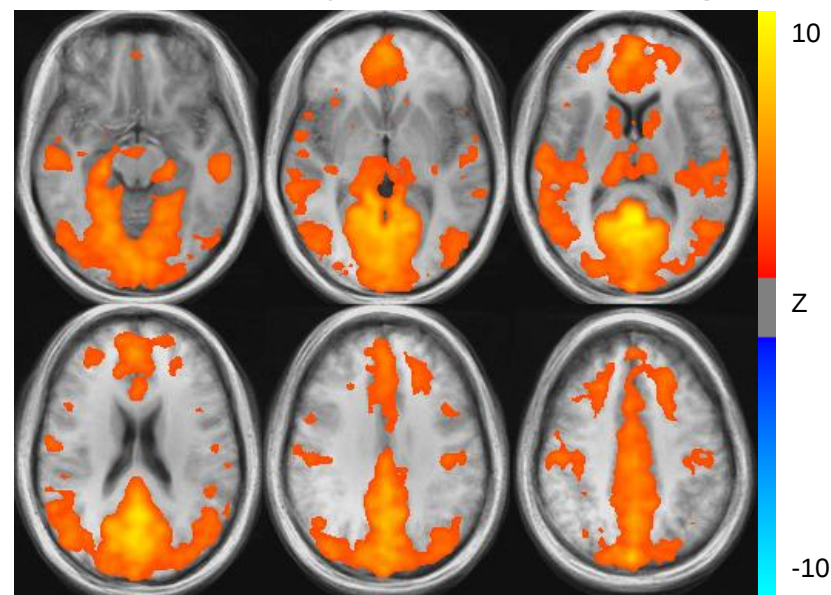


RVT-related changes



group (n=11)

“Connectivity” with Post.Cing.

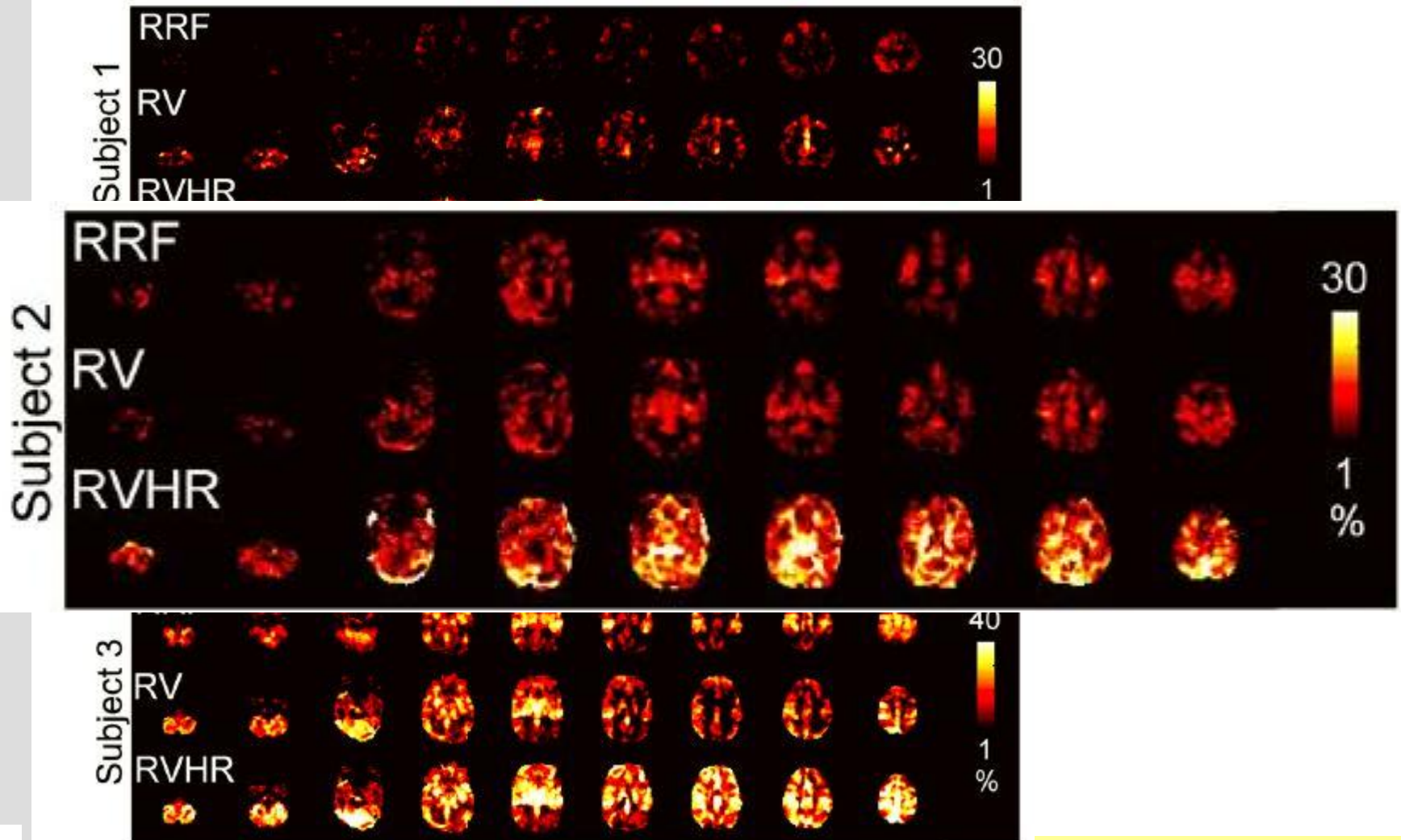


RVT = Respiration Volume per Time

R.M. Birn et al. 2006



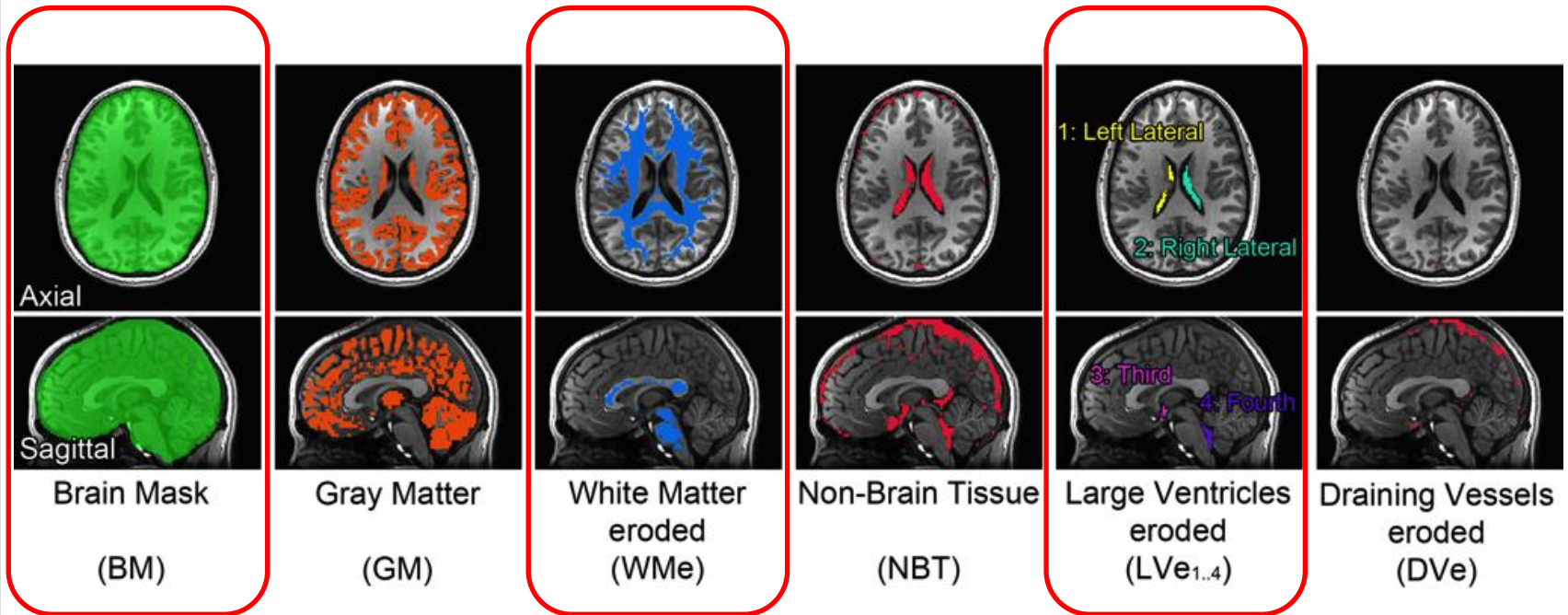
RVHRcor (Respiration Volume + Heart Rate)



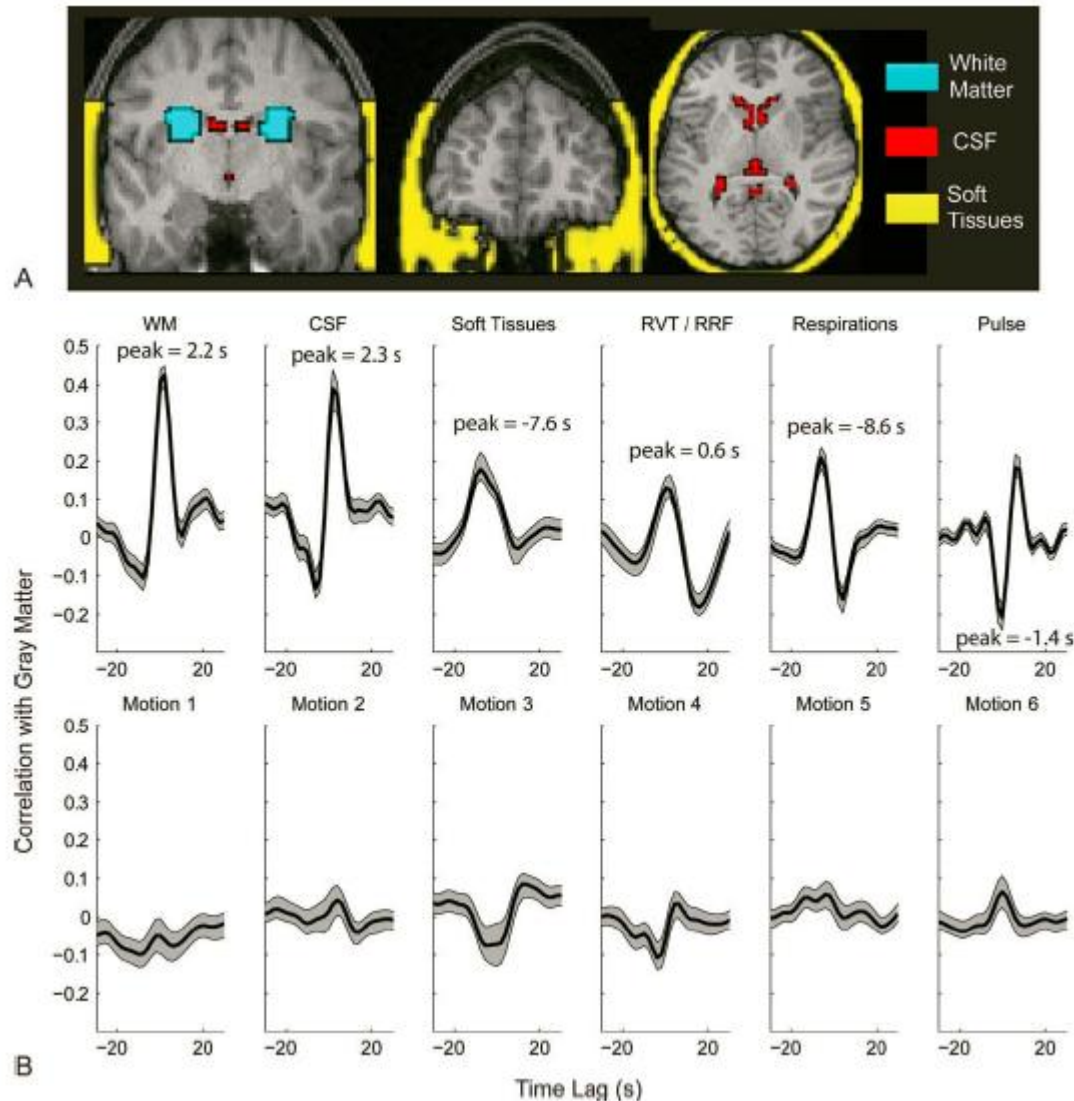
C. Chang et al., Neuroimage 2009



Nuisance Regression



PSTCor (Phase-shifted Soft Tissue Corr.)



*J.S. Anderson et al.,
HBM 32, 2011*



“FIX” (FMRIB’s ICA-based X-noisifier)

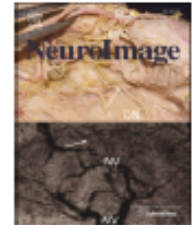
NeuroImage 95 (2014) 232–247



Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg



ICA-based artefact removal and accelerated fMRI acquisition for improved resting state network imaging

Ludovica Griffanti^{a,b,c,*}, Gholamreza Salimi-Khorshidi^a, Christian F. Beckmann^{d,e}, Edward J. Auerbach^f, Gwenaëlle Douaud^a, Claire E. Sexton^g, Enikő Zsoldos^g, Klaus P. Ebmeier^g, Nicola Filippini^{a,g}, Clare E. Mackay^{a,g}, Steen Moeller^f, Junqian Xu^{f,h}, Essa Yacoub^f, Giuseppe Baselli^b, Kamil Ugurbil^f, Karla L. Miller^a, Stephen M. Smith^a

^a FMRIB (Oxford University Centre for Functional MRI of the Brain), UK

^b Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy

^c MR Laboratory, IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy

^d Donders Institute for Brain, Cognition and Behaviour, Radboud University, Nijmegen, The Netherlands

^e MIRA Institute for Biomedical Technology and Technical Medicine, University of Twente, Enschede, The Netherlands

^f Center for Magnetic Resonance Research, University of Minnesota Medical School, Minneapolis, MN, USA

^g Department of Psychiatry, University of Oxford, Oxford, UK

^h Translational and Molecular Imaging Institute, Icahn School of Medicine at Mount Sinai, New York, NY, USA

L. Griffanti, et al., Neuroimage 2014

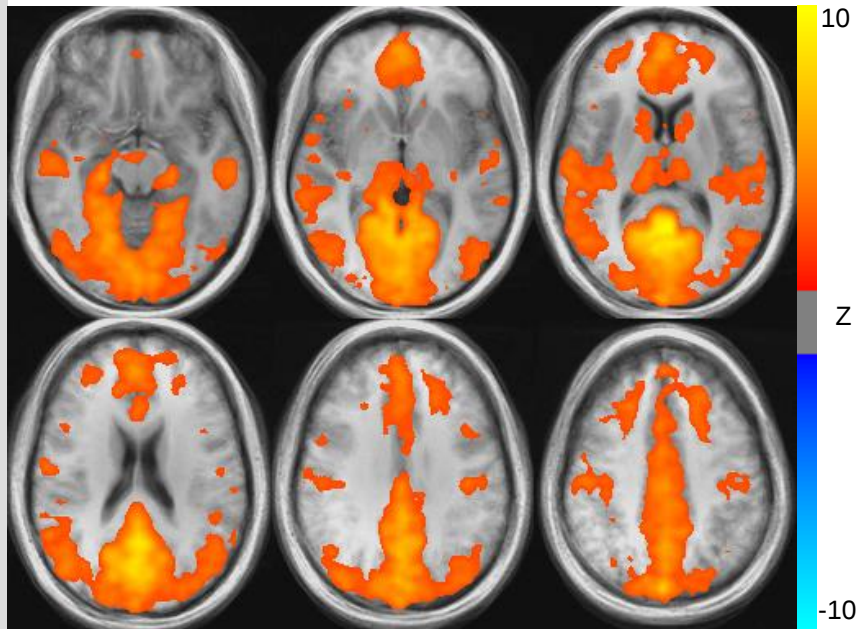


Issues



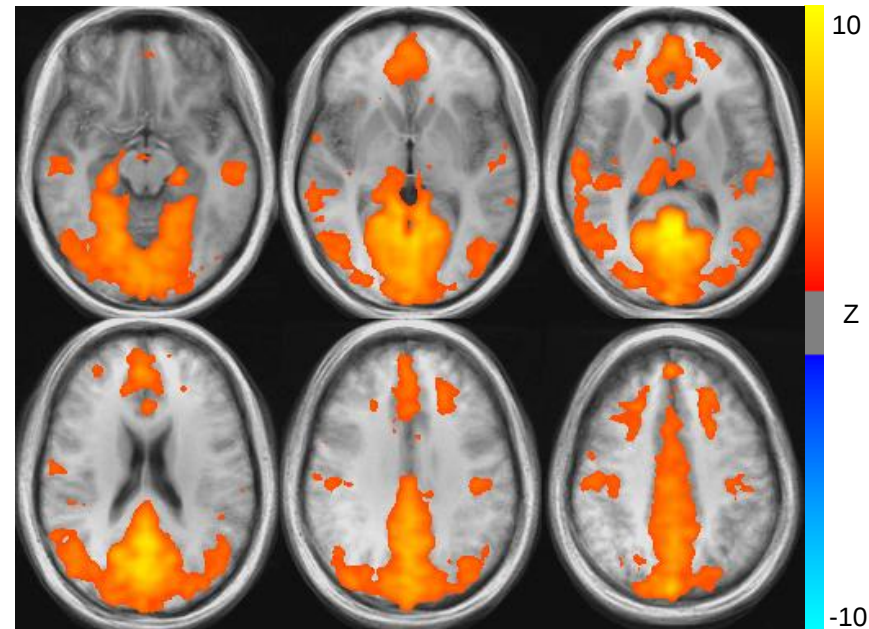
Removing RVT results in only small differences

Correlation (of PC) at Rest



after RETROICOR

Correlation (of PC) at Rest



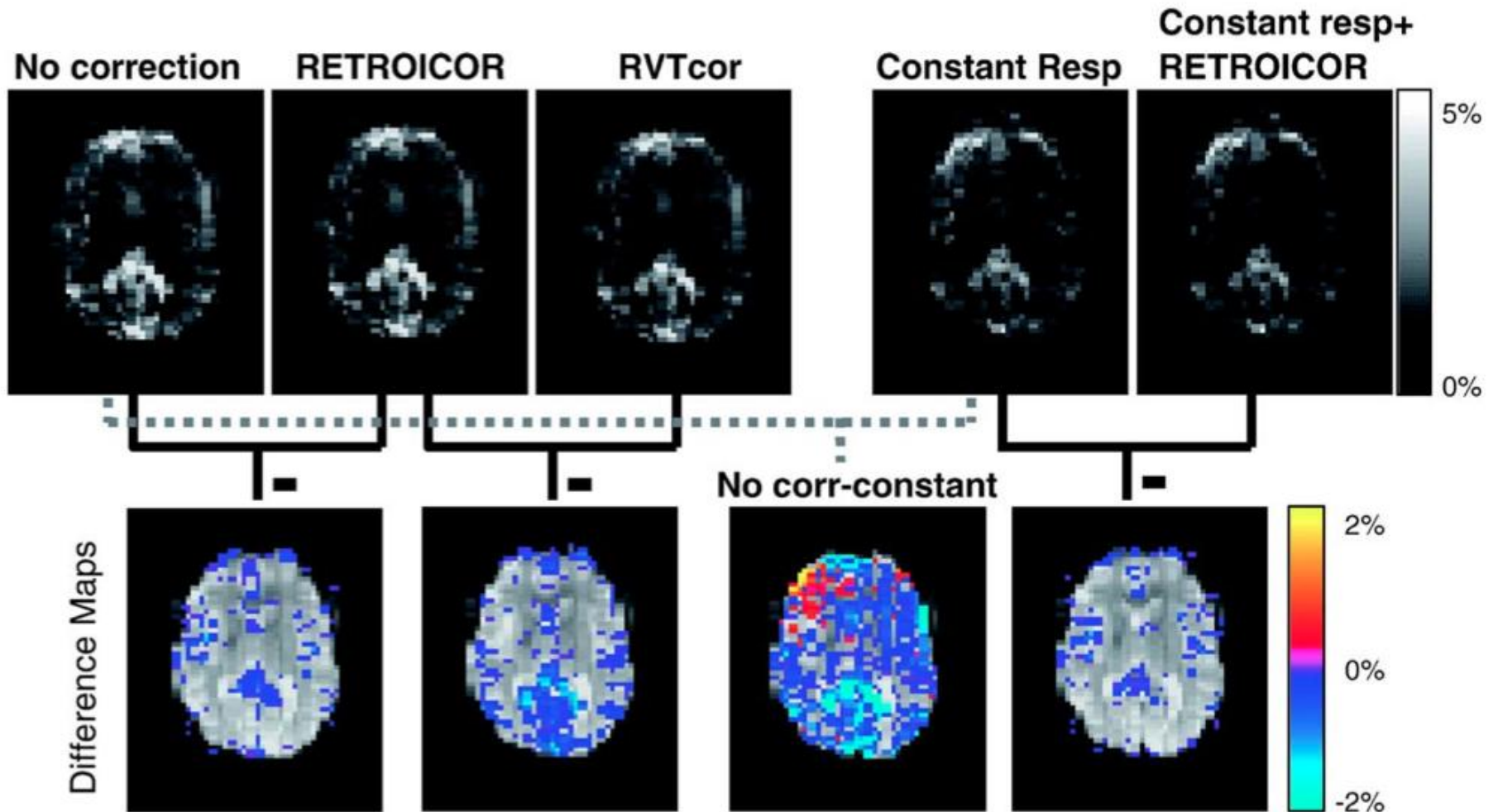
after RETROICOR + RVTcor

... on group maps

Group (n=10)

R.M. Birn et al. 2006

Std. Dev. maps

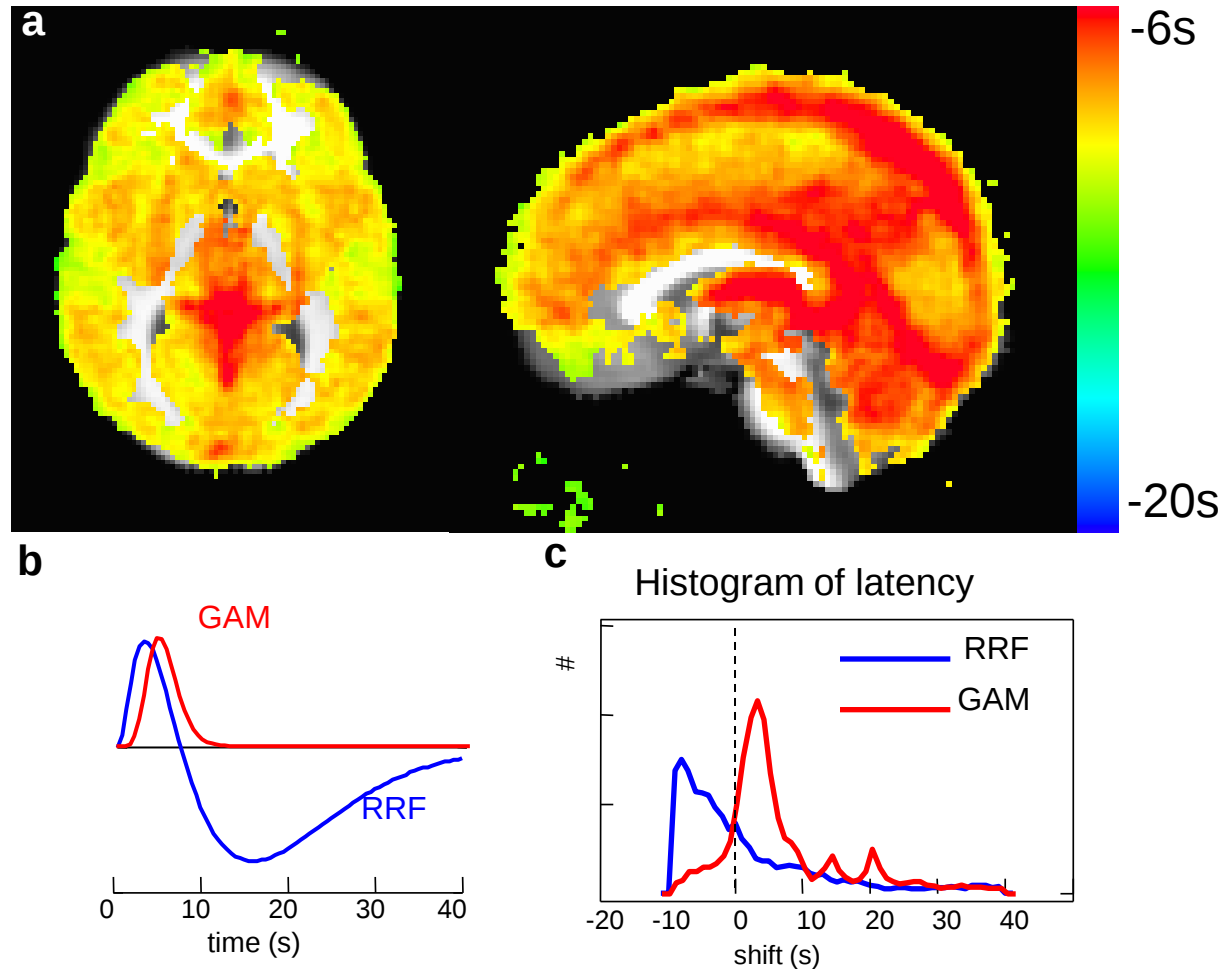


R.M. Birn et al. 2006



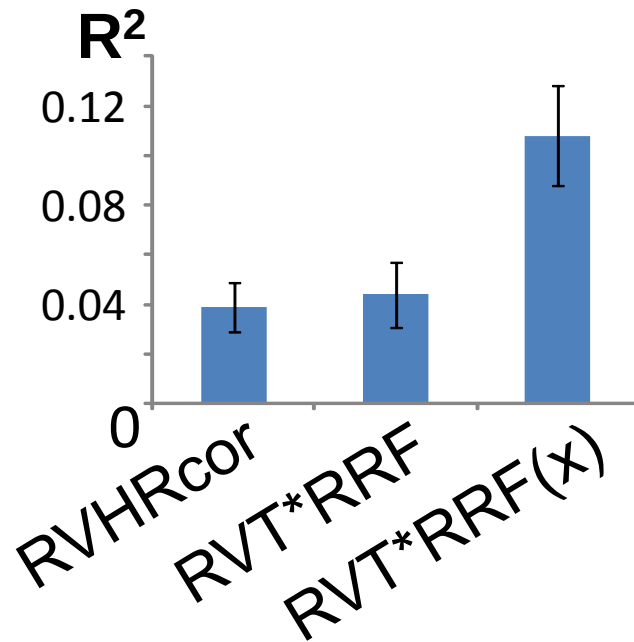
RRF varies across the brain

Optimal latency of Respiration Response Function (RRF)

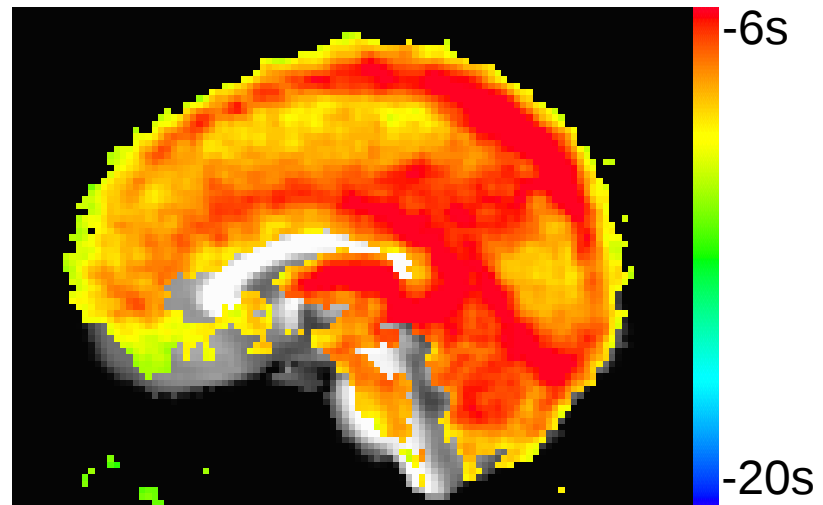


Birn et al., 2008



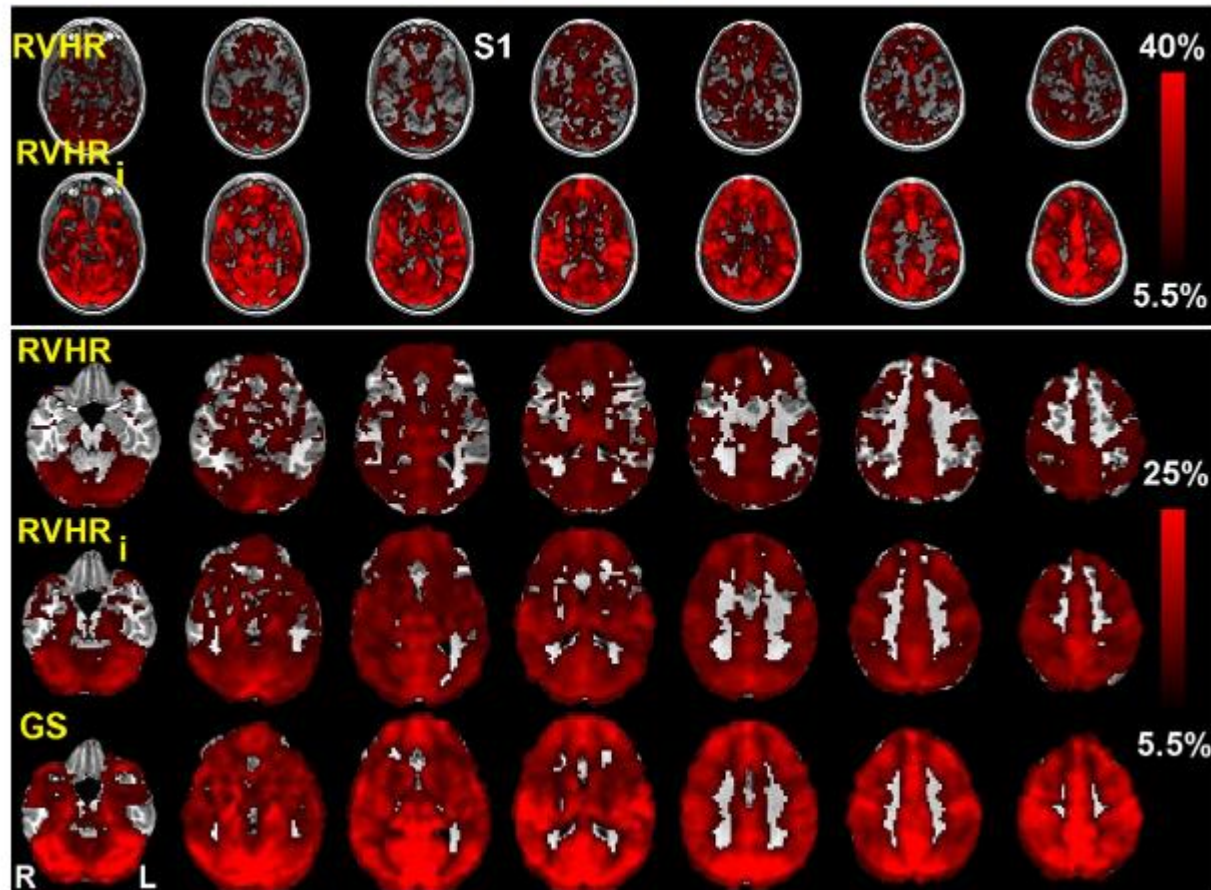


Optimal latency of Respiration Response Function (RRF)



Subject Specific physiological models

M. Falahpour et al. / NeuroImage 72 (2013) 252–264

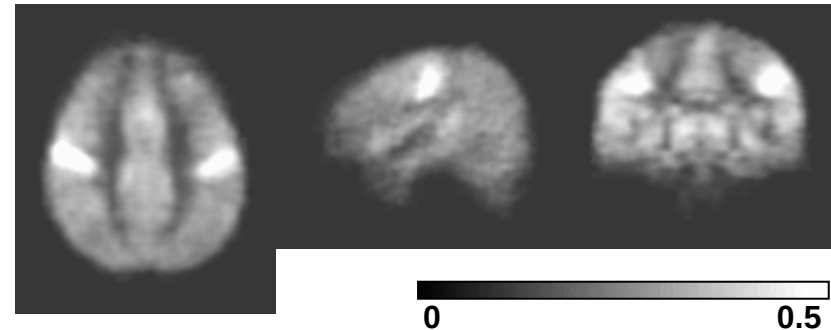
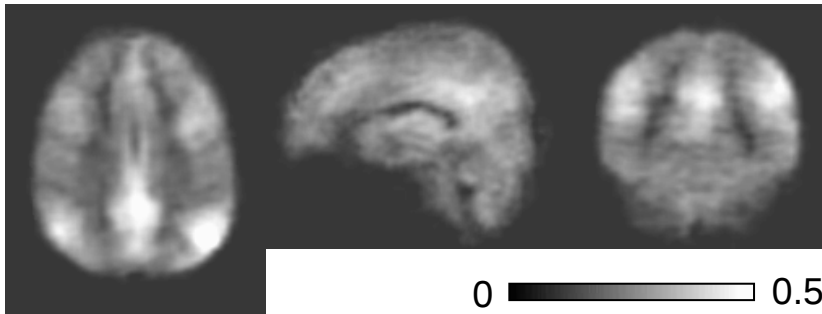


M. Falahpour et al., Neuroimage 2013

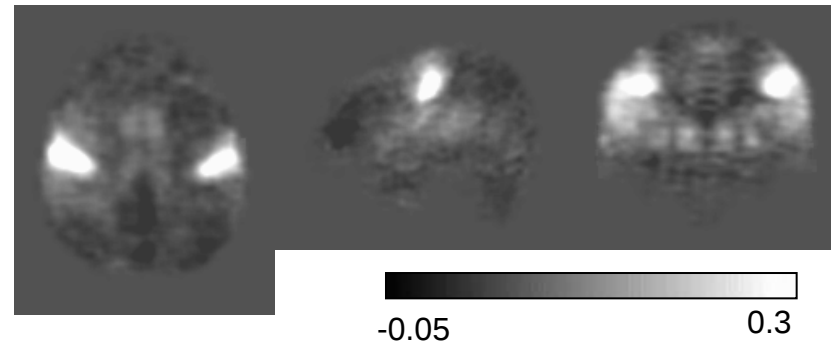
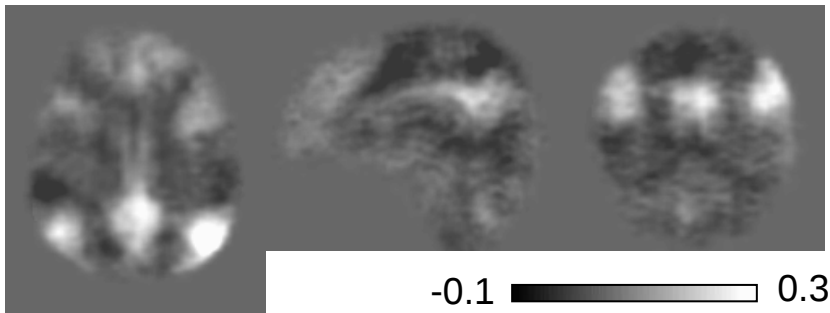
What about global signal regression?

Connectivity maps

without global regression

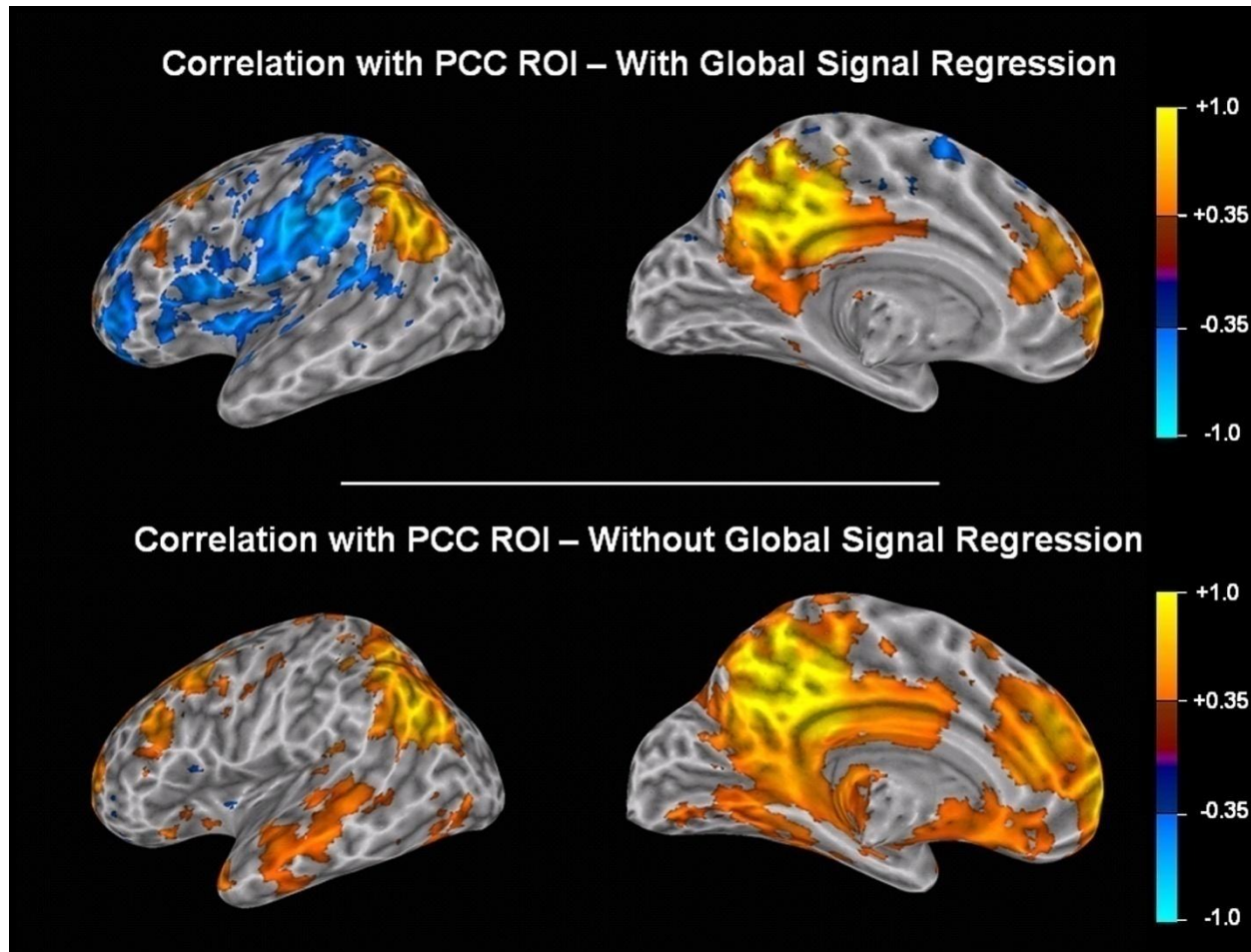


with global regression



Global Signal Regression

Can introduce anti-correlations



K. Murphy, et al., Neuroimage, 2008



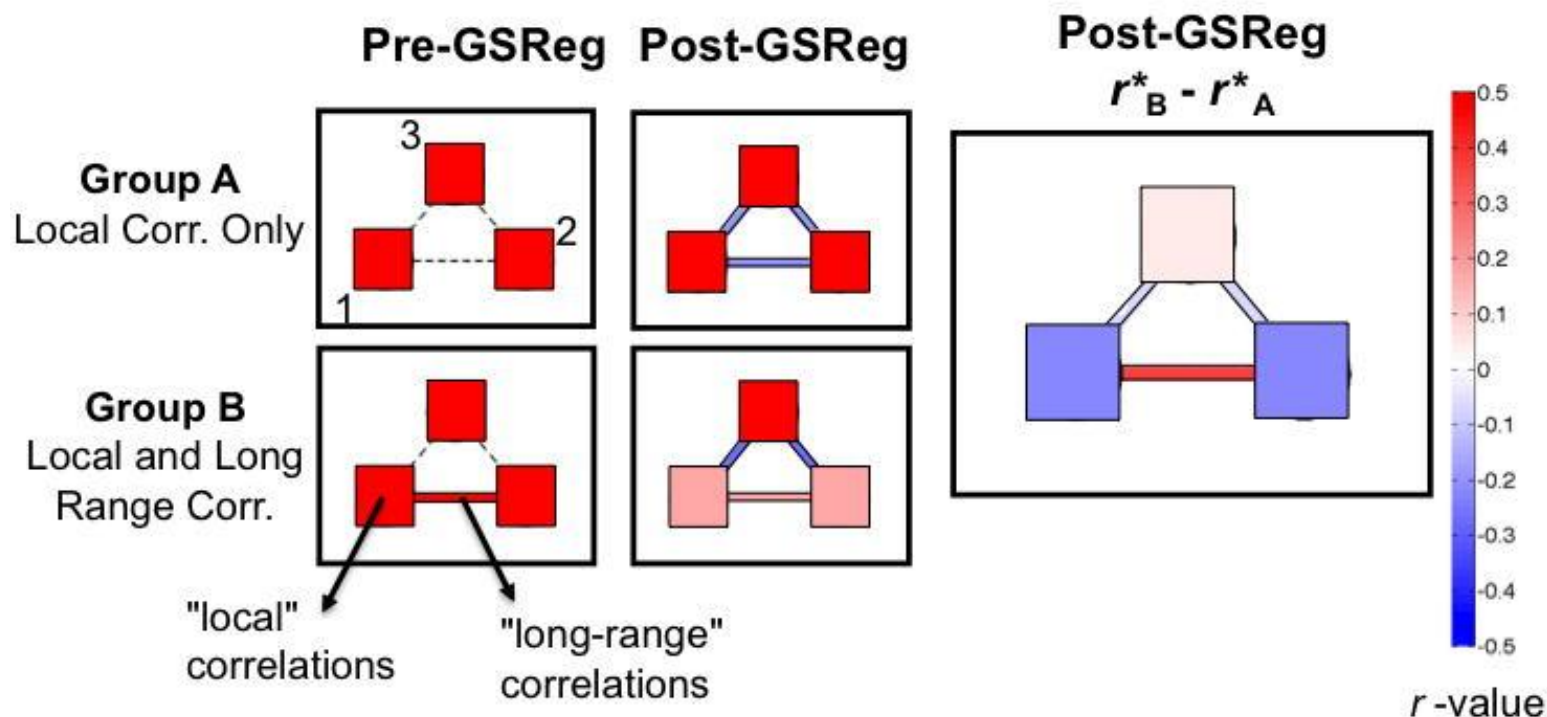
Global Signal Regression

Can alter group differences ...under certain conditions

Illustrative Model 3:

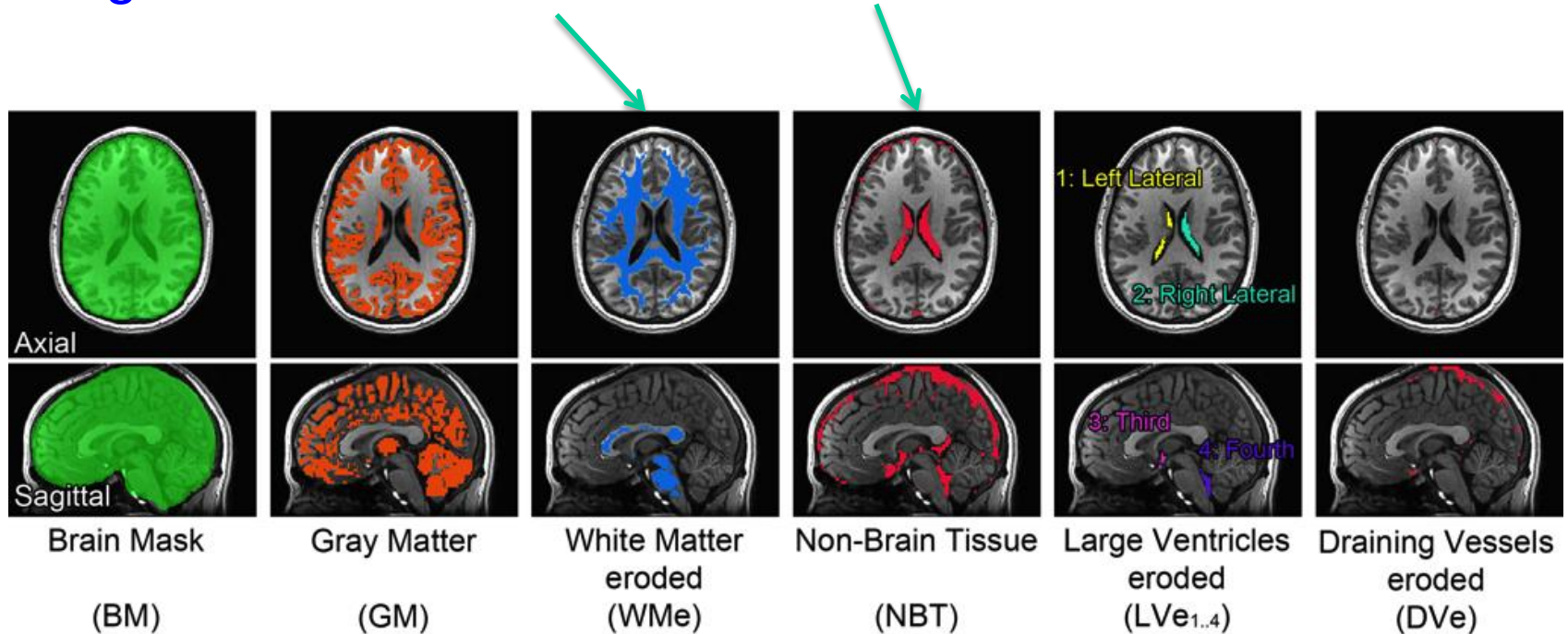
Contrast of correlations between groups A and B

'long-range' correlations in Group B only



Alternatives to Global Signal Regression

Regress out white matter and CSF



At what stage should physio correction be done?

- Preprocessing
 - Motion correction
 - Physiological noise correction
 - Slice time correction
 - Nuisance Regression
 - Spatial Smoothing
 - Convert to percent signal change
 - Temporal filter
- Define ROI (seed)
- Average EPI time course over ROI
- Regression

T.B. Jones et al., Neuroimage 42, 2008



Should we perform physio corrections?

- Reduces fluctuations related to heart beat and respiration
 - Reduce false positives
 - Reduce false negatives
- Some physiological fluctuations are associated with neuronal activity
 - E.g. Heart rate variability

This is still an open question in the field

