ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

University of Zurich[UZH]

Translational Neuromodeling Unit

Physiological Noise Correction for fMRI

- *an Introduction to the PhysIO Toolbox*

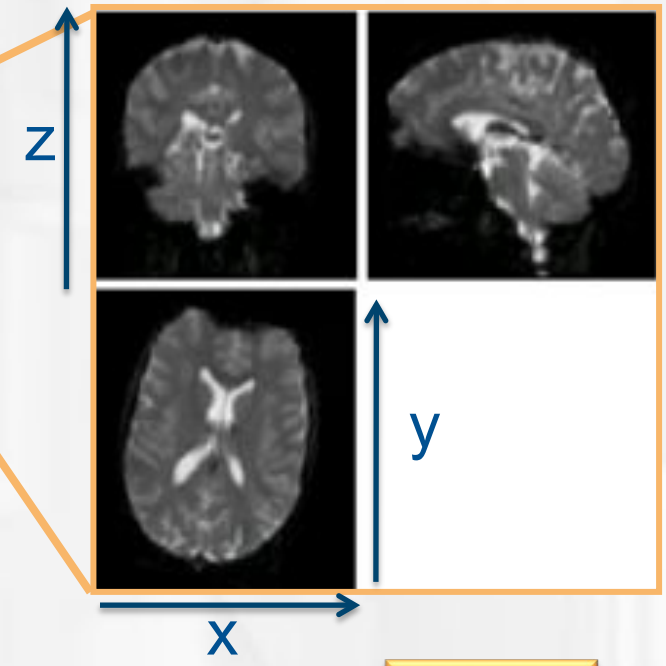
Lars Kasper

April 30th , 2014

The PhysIO Toolbox

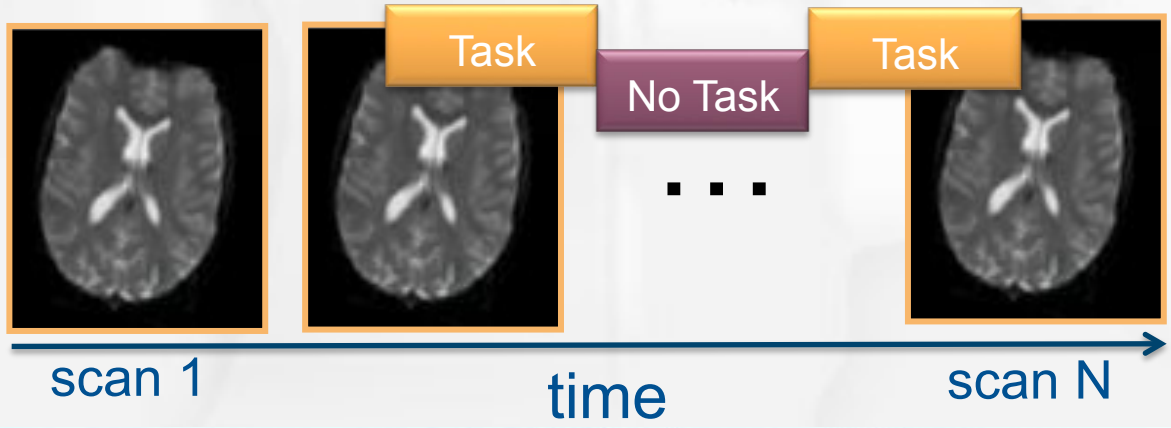
- Developed at the Translational Neuromodeling Unit (TNU) since 2008
  - Lead programmer: Lars Kasper (TNU)
  - Contributors: Jakob Heinzle (TNU), Steffen Bollmann (KiSpi Zurich)
- Part of the TNU «TAPAS» software suite
- Used at the TNU, in Zurich and beyond by ~30 researchers
- Current version:
  - http://www.translationalneuromodeling.org/tapas/
- Documentation & Example Data:
  - http://www.translationalneuromodeling.org/software/documentation/
  - http://www.translationalneuromodeling.org/software/tapas-data/

fMRI = Acquiring Movies



- …of three-dimensional Blood Oxygen-Level Dependent (BOLD) contrast images

- Run/Session: Time Series of Images

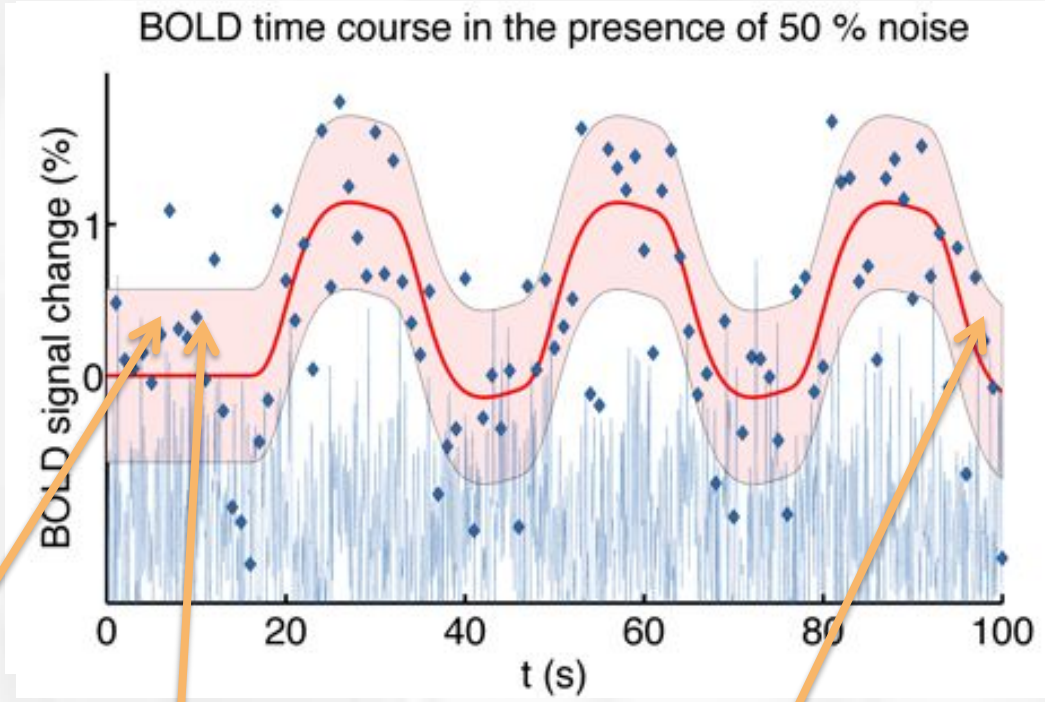


fMRI = Acquiring Movies

- The Localized Time-series is the Fundamental Information Unit of fMRI

Signal: Fluctuation through Blood oxygen level dependent (BOLD) contrast

Noise: All other fluctuations



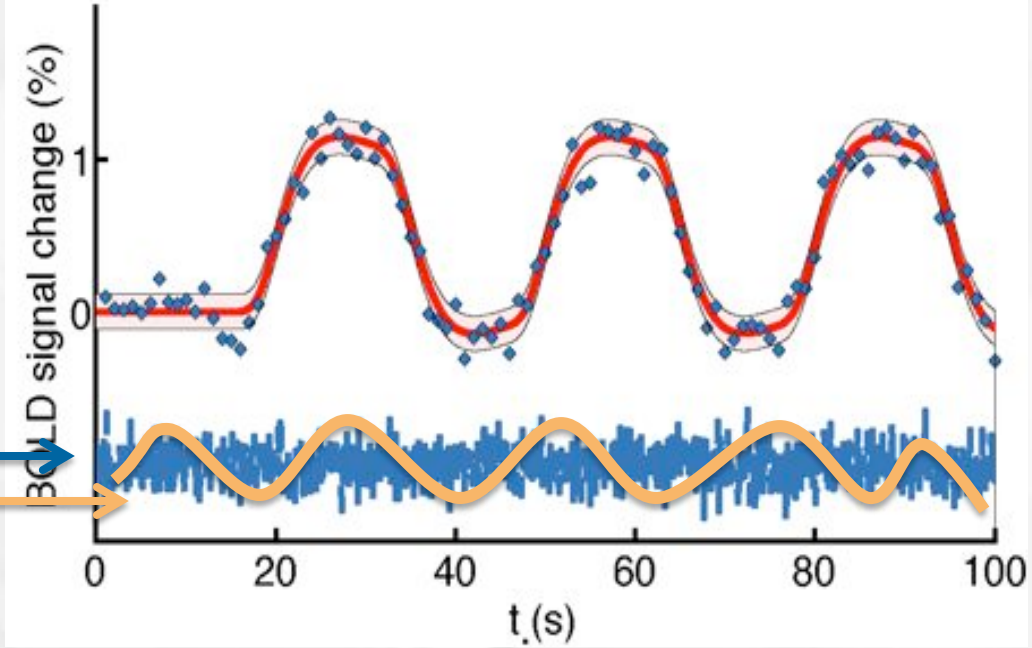
- Run/Session: Time Series of Images

Noise Categories & Reduction

- Thermal Noise
  - temporally uncorrelated
  - reduced SNR ➔ risk of false negatives
  - Remedy: Spatial Smoothing

Noise: All other fluctuations

- "Structured" Noise
  - temporally correlated
  - reduced SNR ➔ risk of false negatives
  - correlated with task ➔risk of false positives
  - Remedy: Noise Modelling (e.g. GLM)



Inference = Signal-To-Noise

$$t = \frac{\beta}{\sqrt{\hat{\sigma}_\varepsilon^2 (X^T X)^{-1}}} = \frac{\beta \|x\|}{\hat{\sigma}_\varepsilon}$$

$$F = \frac{N - M}{M_1} \cdot \frac{(\sigma_S^2 + \sigma_N^2) - \sigma_N^2}{\sigma_N^2}$$

The Problem: Physiological Noise

- Cardiac effects
- Respiratory effects

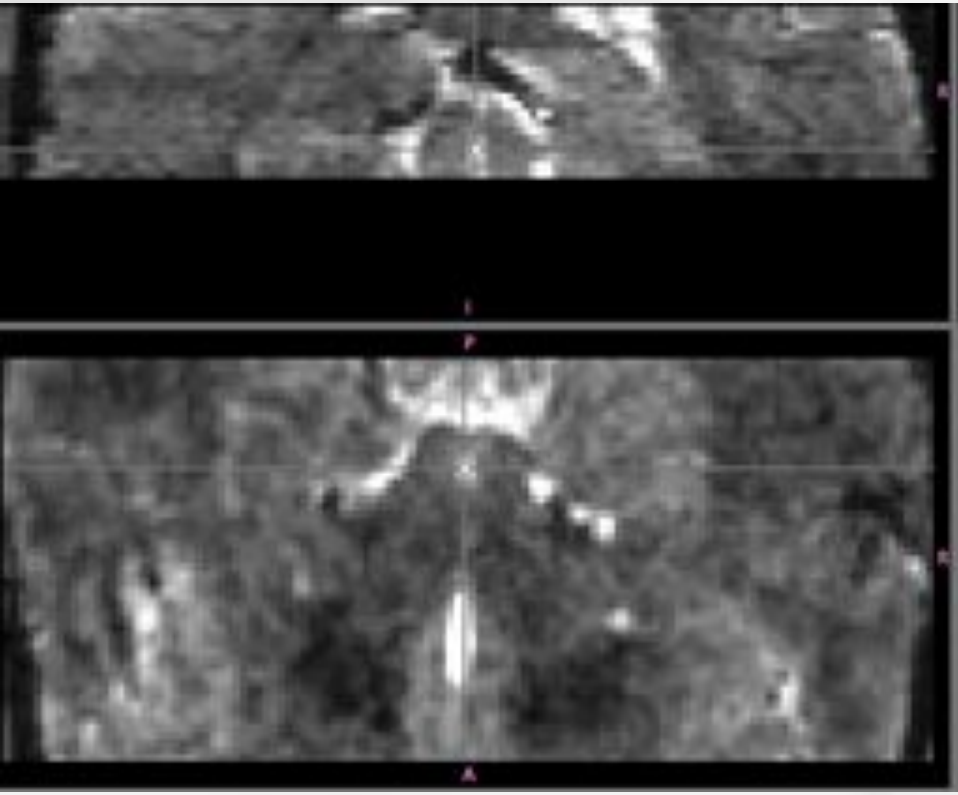
The Problem: Physiological Noise

- Cardiac effects
  - Systole:
    - Blood pumped into brain, vessel volume increases: pulsatile vessels
    - CSF pushed down: pulsatile CSF
  - Diastole:
    - Vessel volume decreases
    - CSF flows back into "void" brain volume

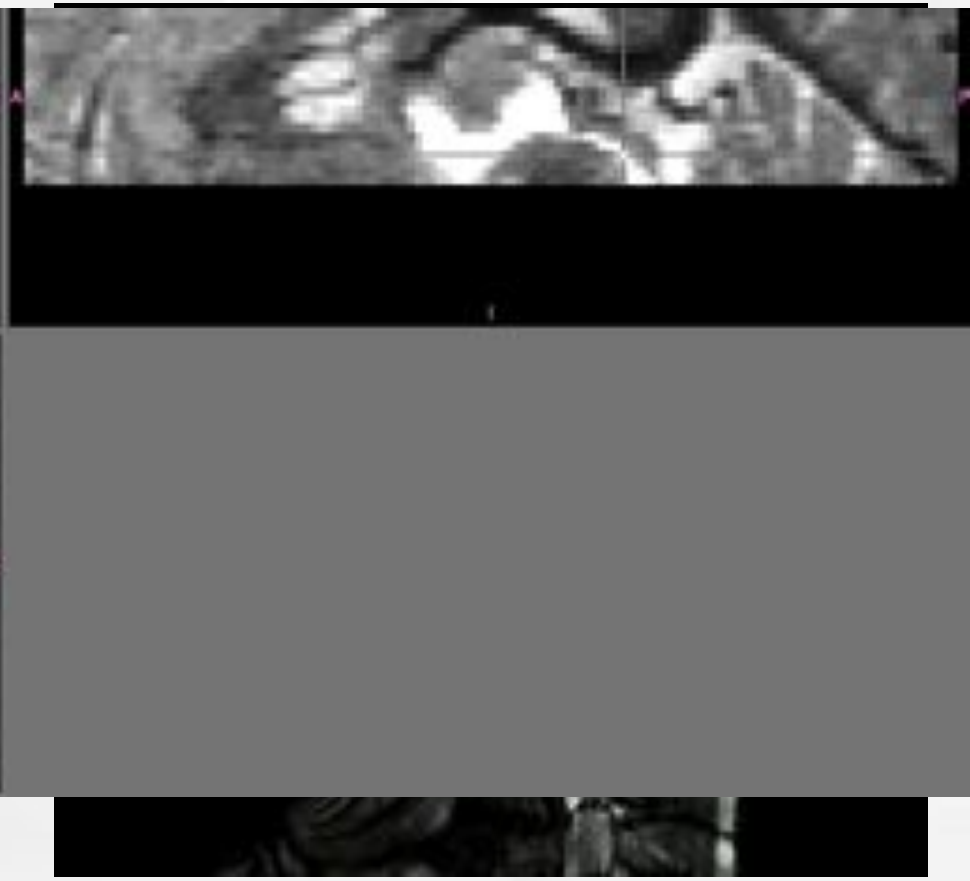
A Cardiac Cycle in the Brain

The Problem: Physiological Noise

Triggered High-Resolution fMRI

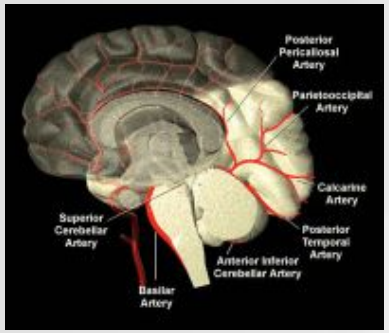


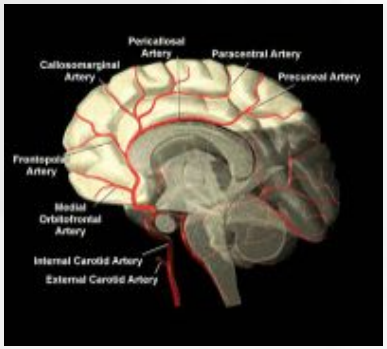
A Cardiac Cycle in the Brain

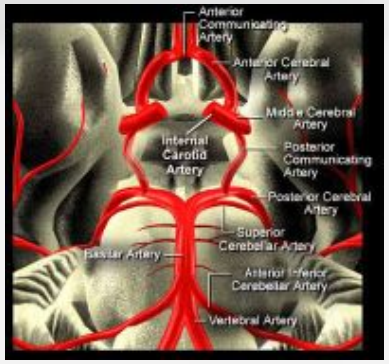


The Problem: Physiological Noise

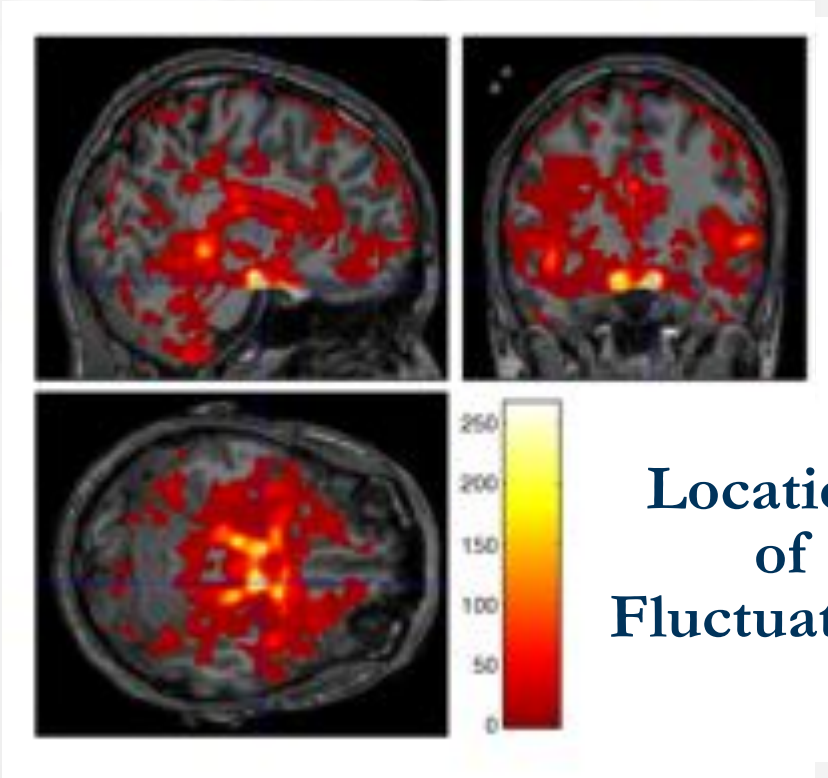
- Cardiac effects





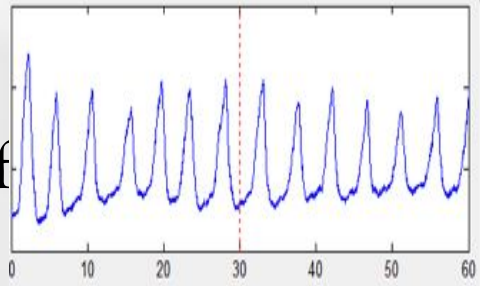


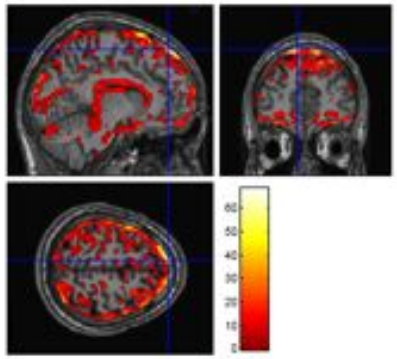
Vessel Anatomy

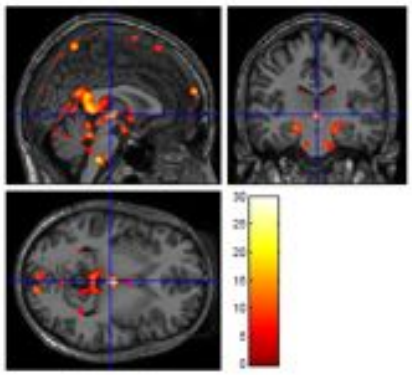


Locations of Fluctuations

The Problem: Physiological Noise



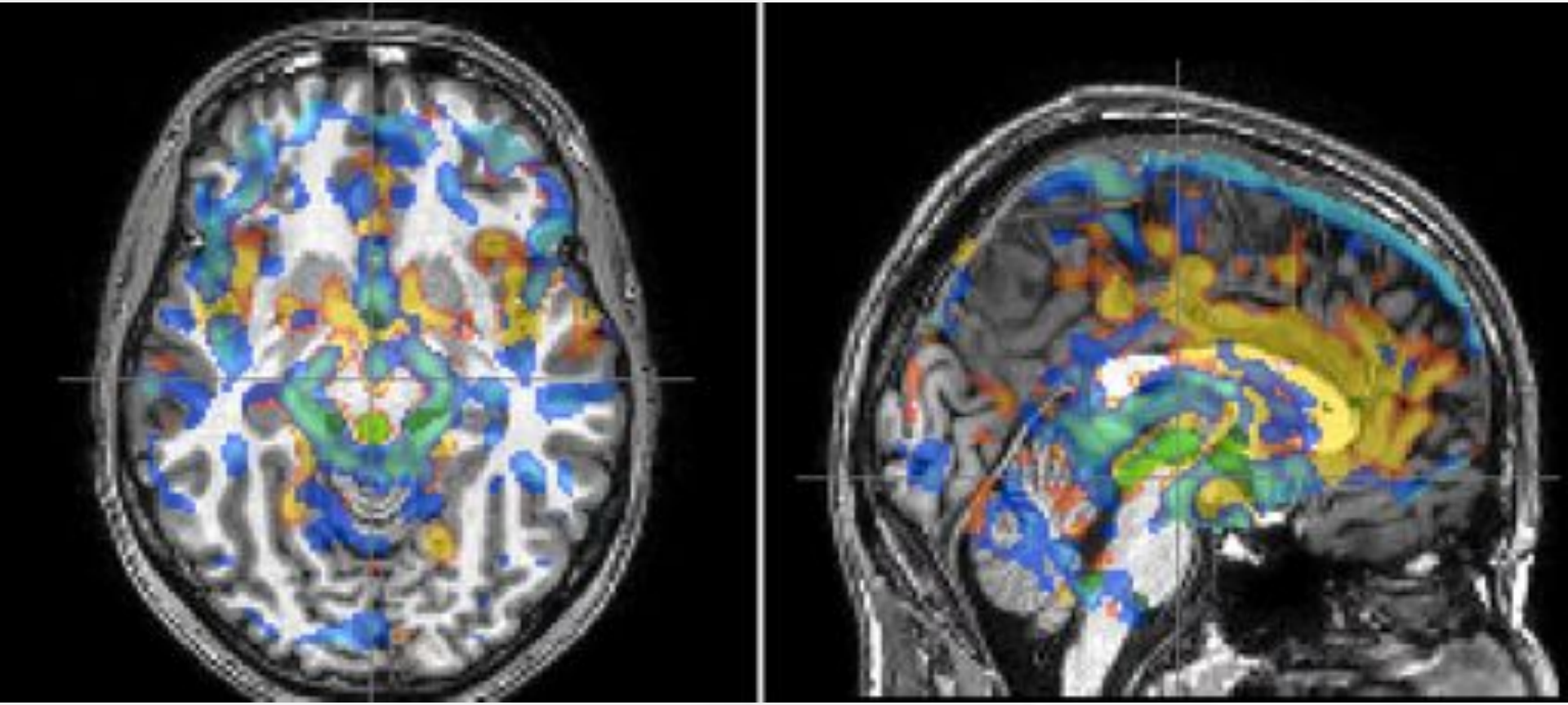




- Respiratory effects
  - Chest (&head) moves with respiratory cycle
  - Changes in lung volume change encoding magnetic field for MR
    - Geometric distortion/scaling
  - Respiratory-sinus arrythmia
    - Heart beats faster during inhalation

Relevance for Neuromodulation

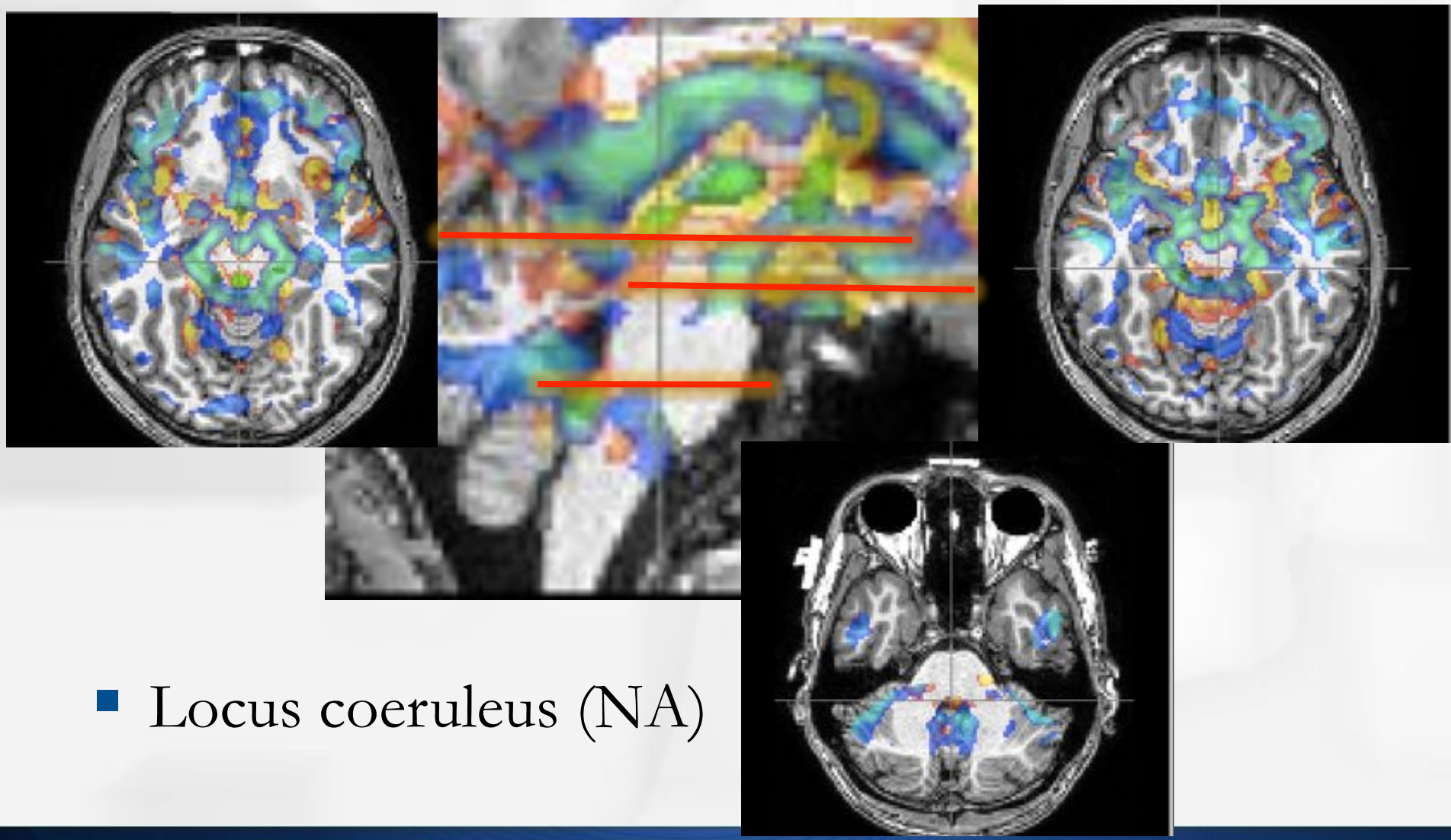
Translational Neuromodeling Unit



Relevance for Neuromodulation

Translational Neuromodeling Unit

- VTA (DA)
- Raphe Nuclei (5-HT)



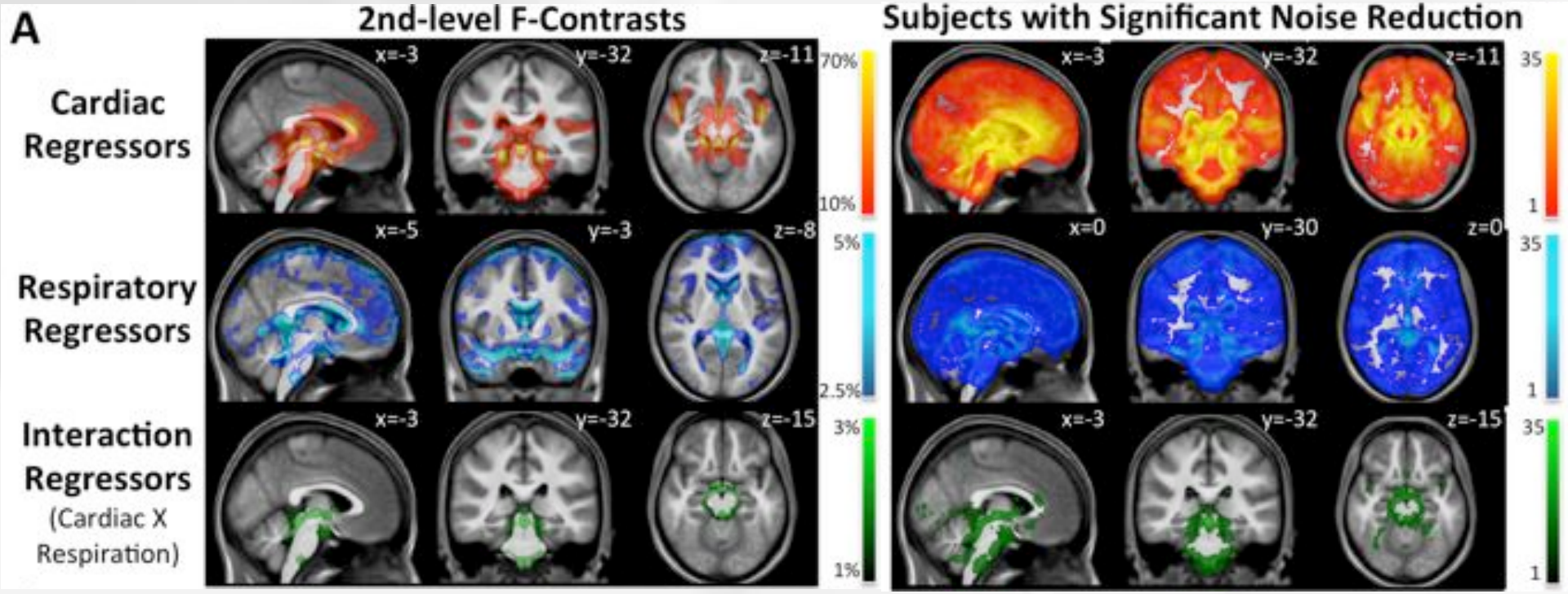
- Locus coeruleus (NA)

Group Level Impact PhysIO

Translational Neuromodeling Unit

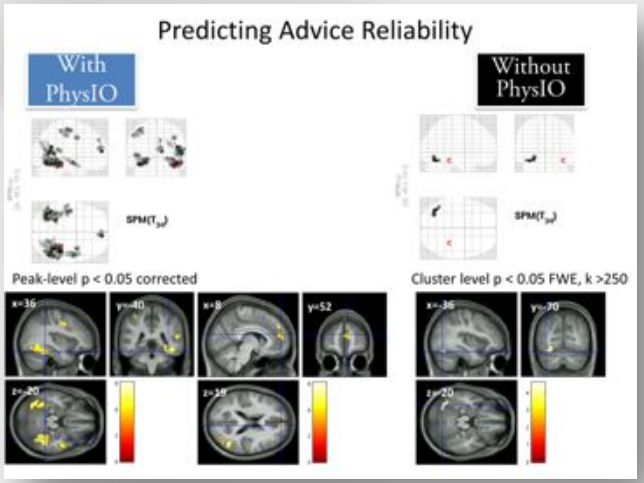
- Andreea Diaconescu (TNU): Social Learning Experiment

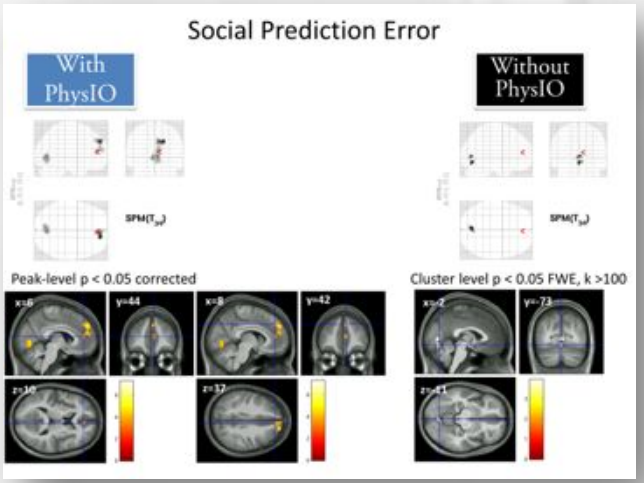
  2012-2014

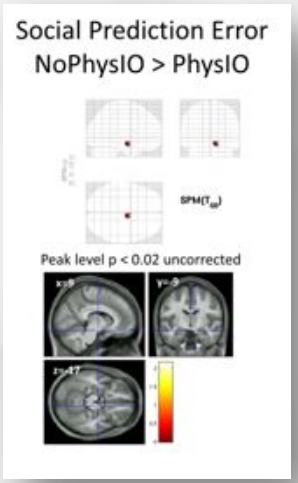


When? – PhysIO experience

- Andreea Diaconescu (TNU): Social Learning
  - Higher sensitivity for group effects (N=35)
    - Prediction of advice reliability: dmPFC, bilateral FFA
    - Prediction error: dmPFC
  - Less false/ambiguous positives:
    - Brainstem (Substantia Nigra)







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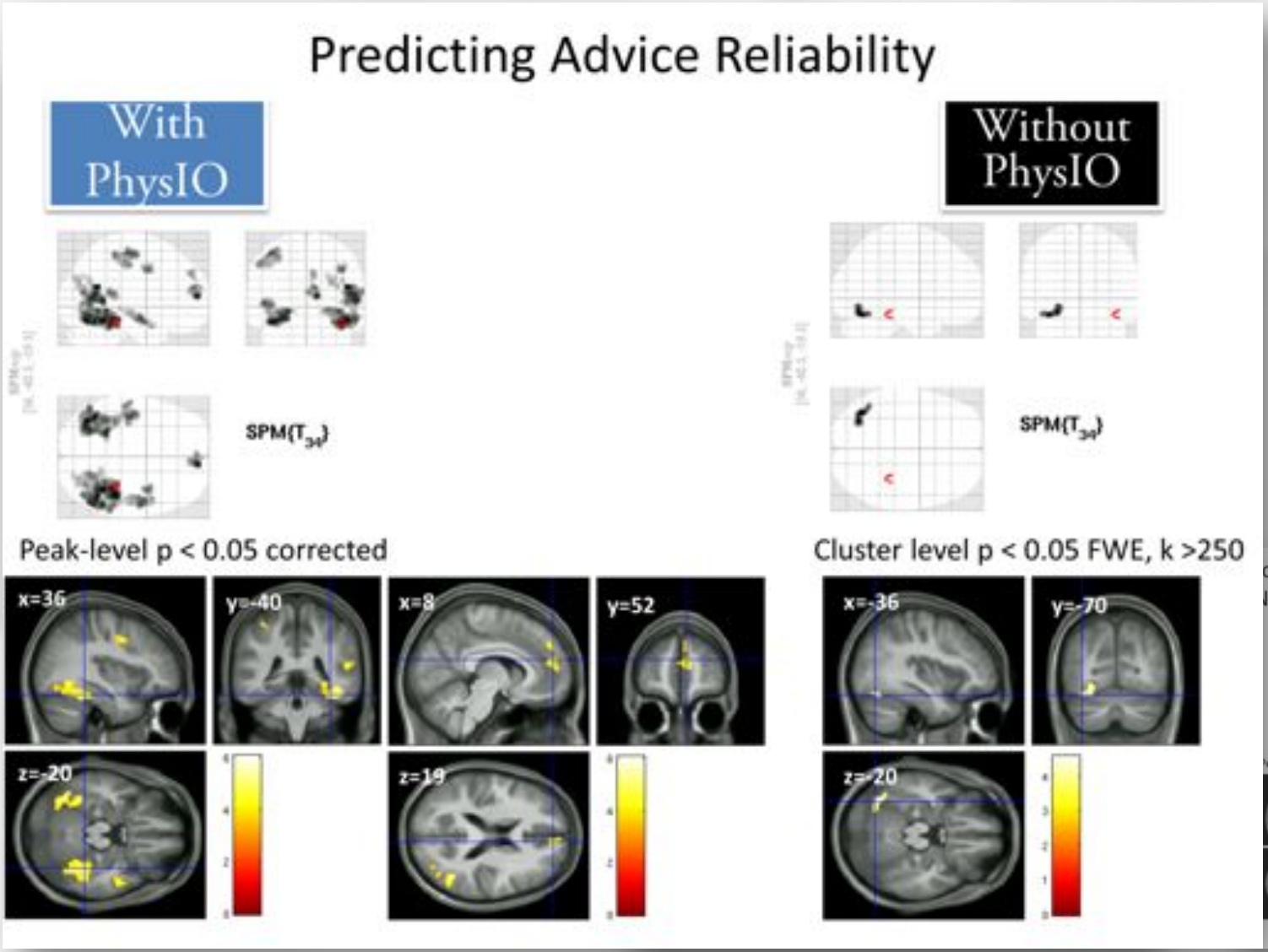

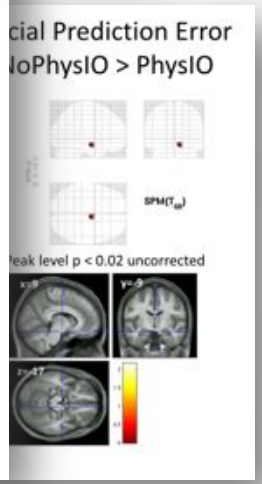

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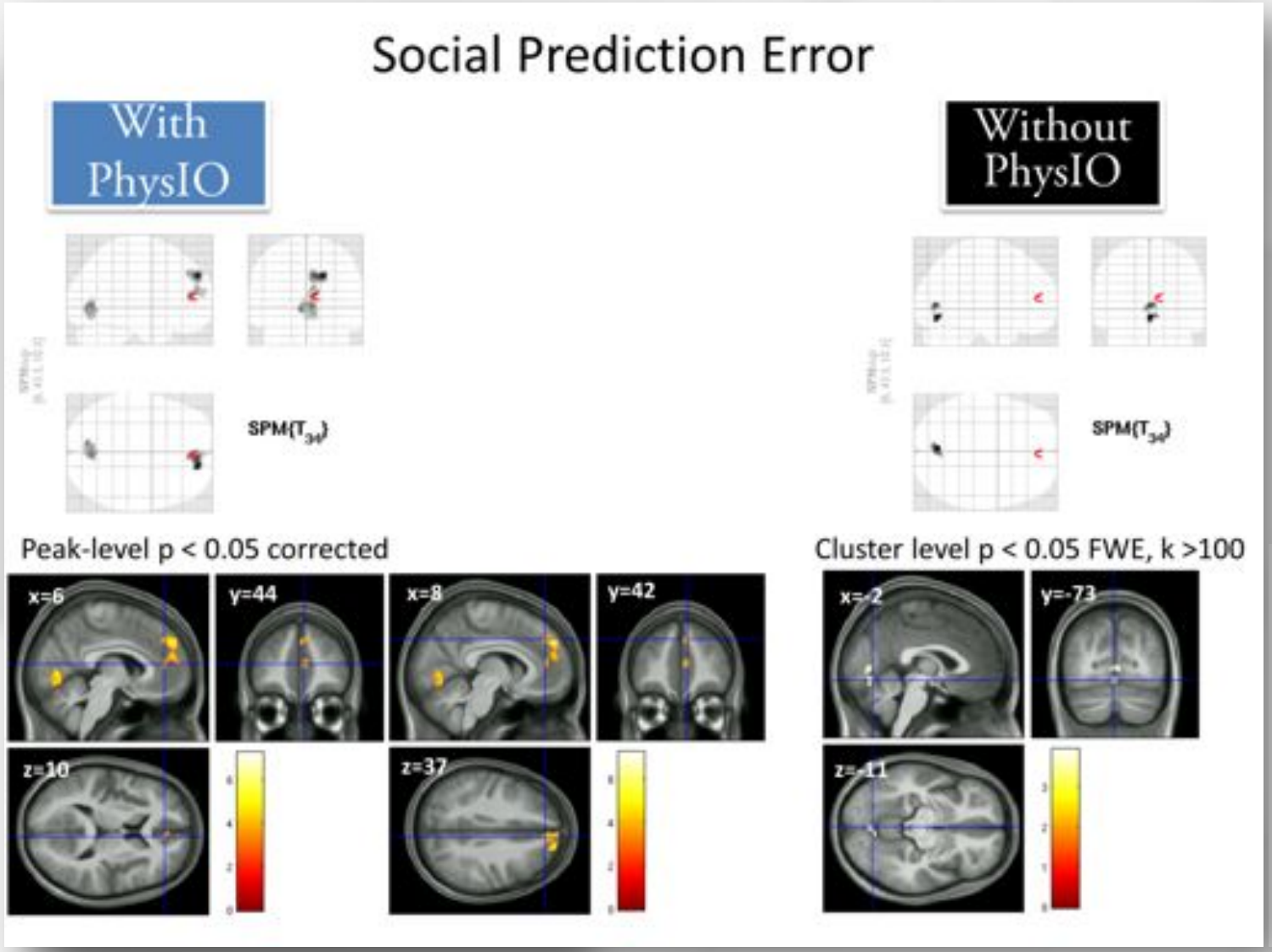

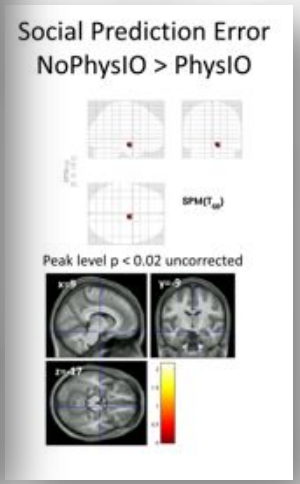

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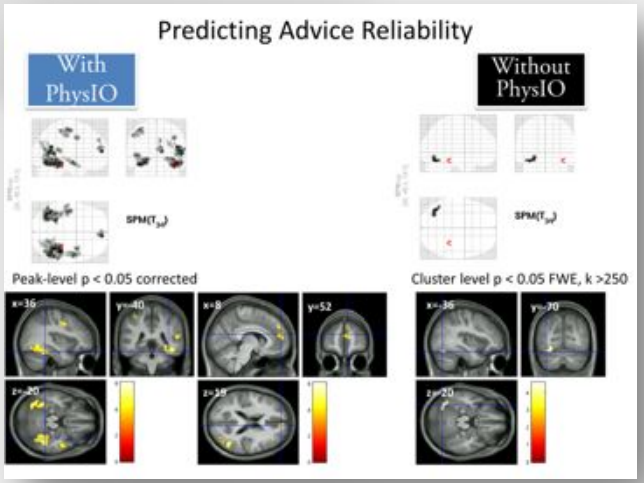
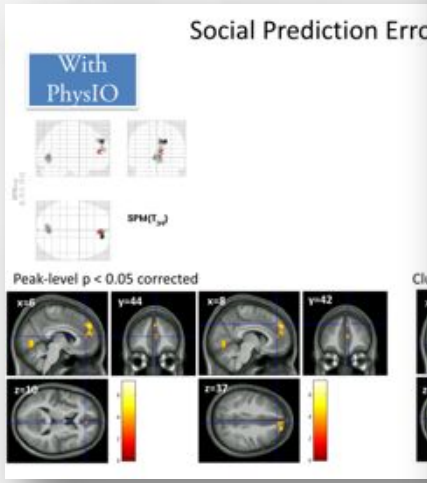
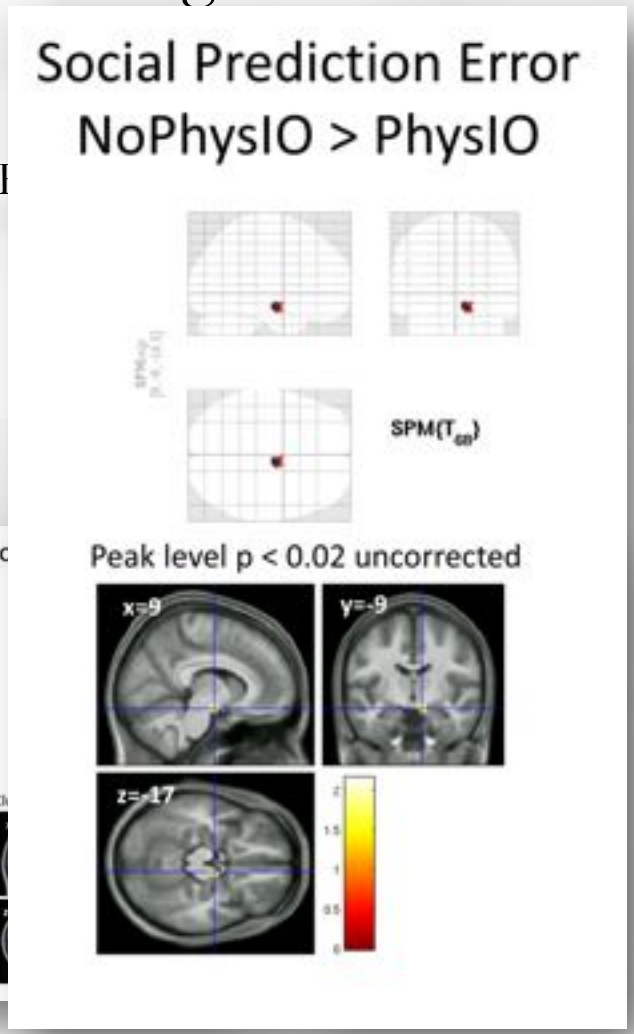


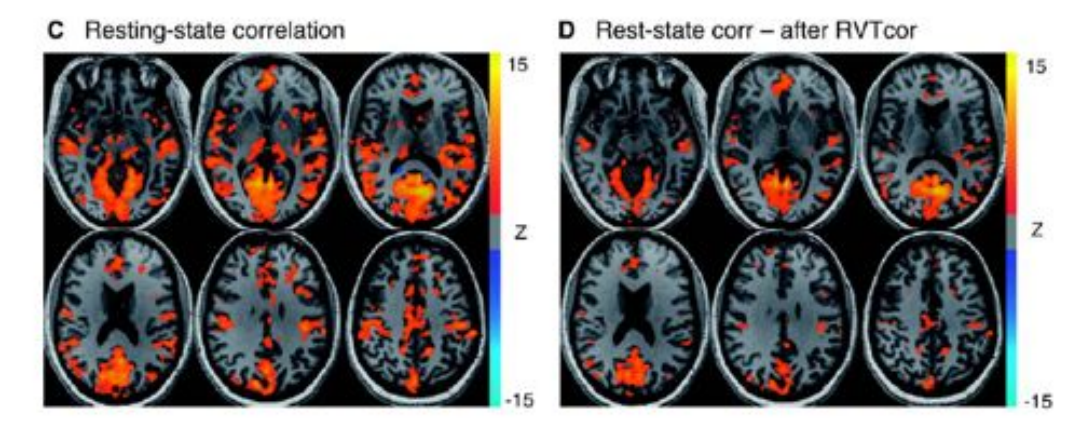




When? – Literature Evidence

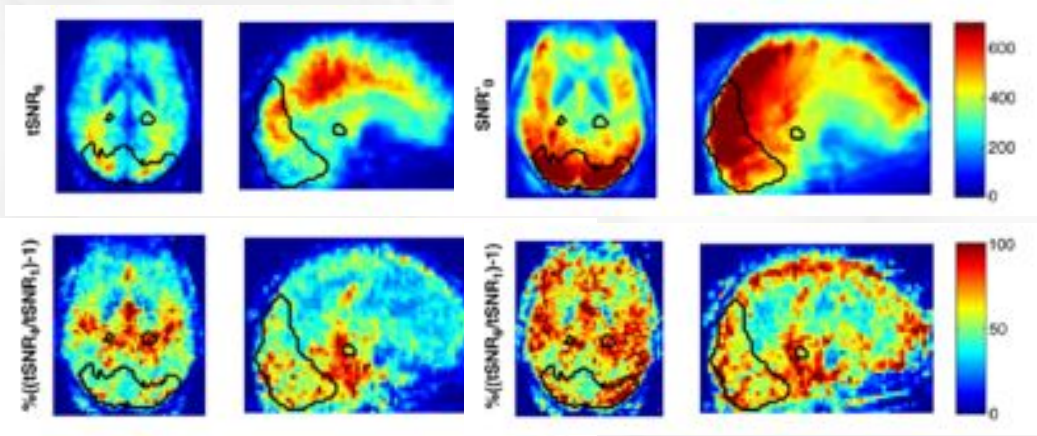
Resting-state:

- Birn, R. M. "The Role of Physiological Noise in Resting-state Functional Connectivity." *NeuroImage 62*, 2012
- Birn, R. M., et al. "Separating Respiratory-variation-related Fluctuations from Neuronal-activity-related Fluctuations in fMRI." *NeuroImage 31*, 2006

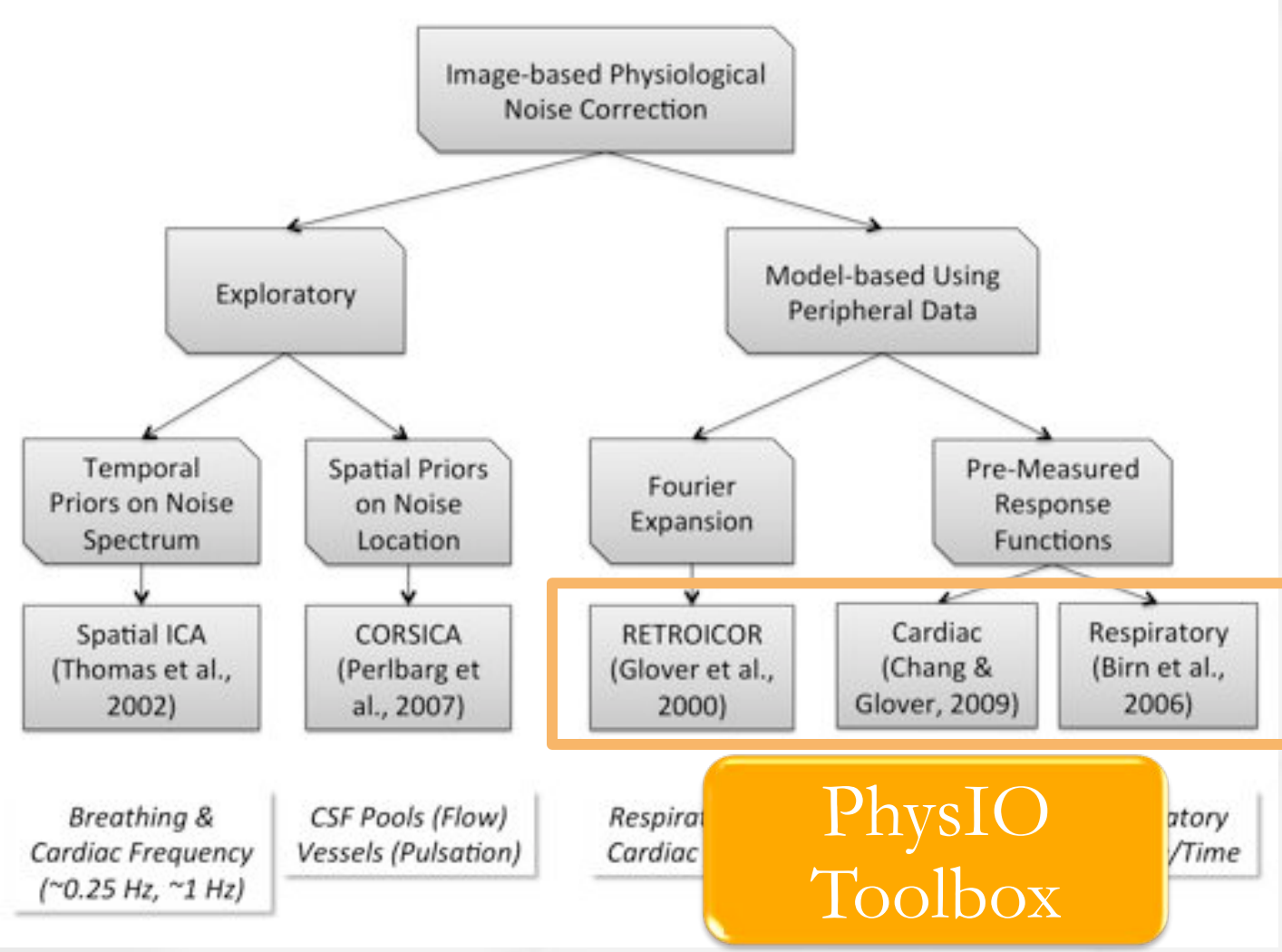


Task-based:

- Hutton, C., et al. "The Impact of Physiological Noise Correction on fMRI at 7 T." *NeuroImage 57*, 2011:



The Solution: Image-based Physiological Noise Correction



Noise Modelling

Translational Neuromodeling Unit

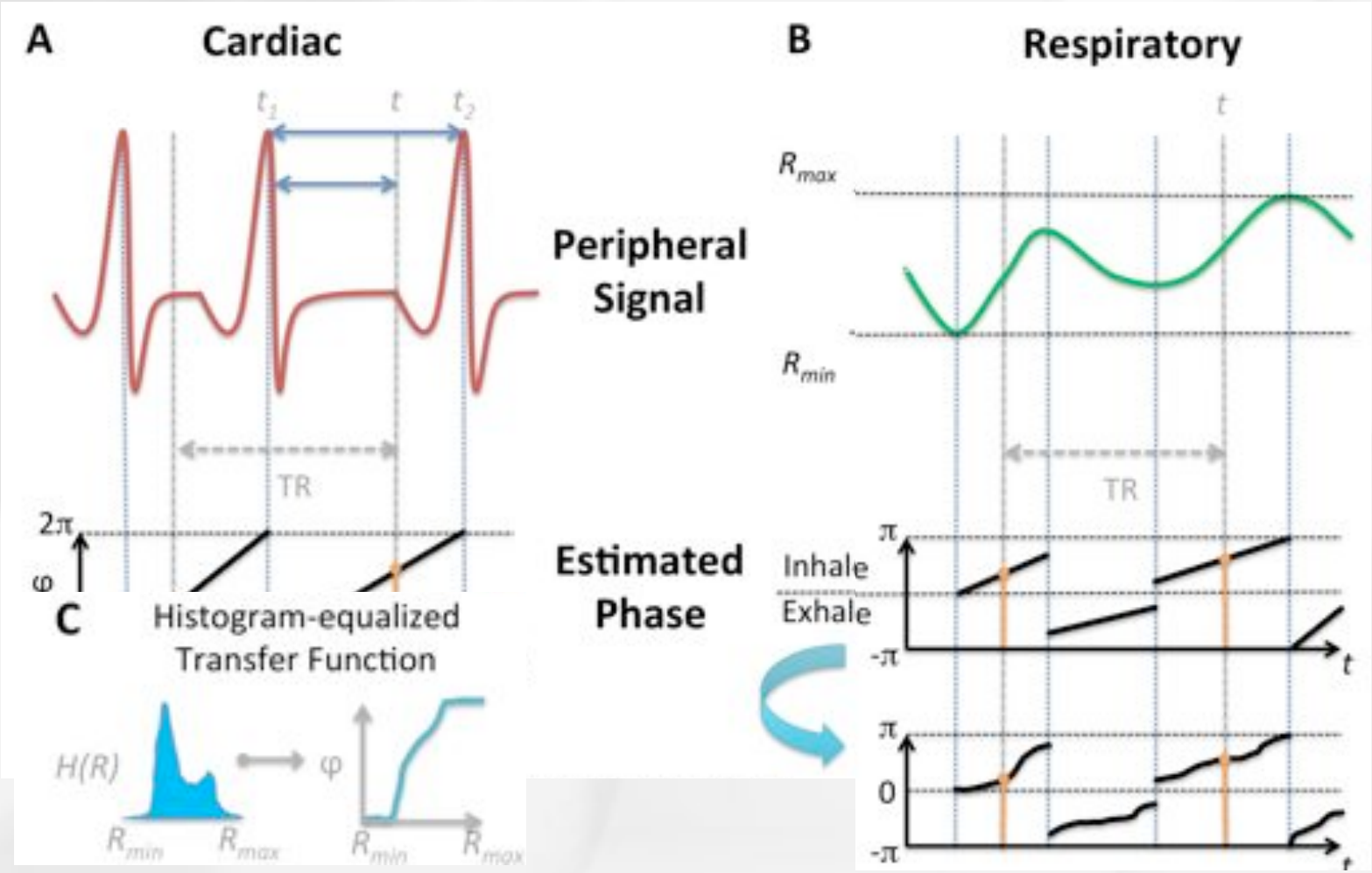
RETROspective Image CORrection	Cardiac Response Function	Respiratory Response Function
▪ Cardiac/respiratory phase φ_c φ_r	▪ Heart Rate	▪ Resp. Volume per Time
▪ Fourier expansion (cosine/sine)	▪ convolved with CRF	▪ convolved with RRF

- evaluated at 1 time point (slice) per volume = regressor

Noise Modelling

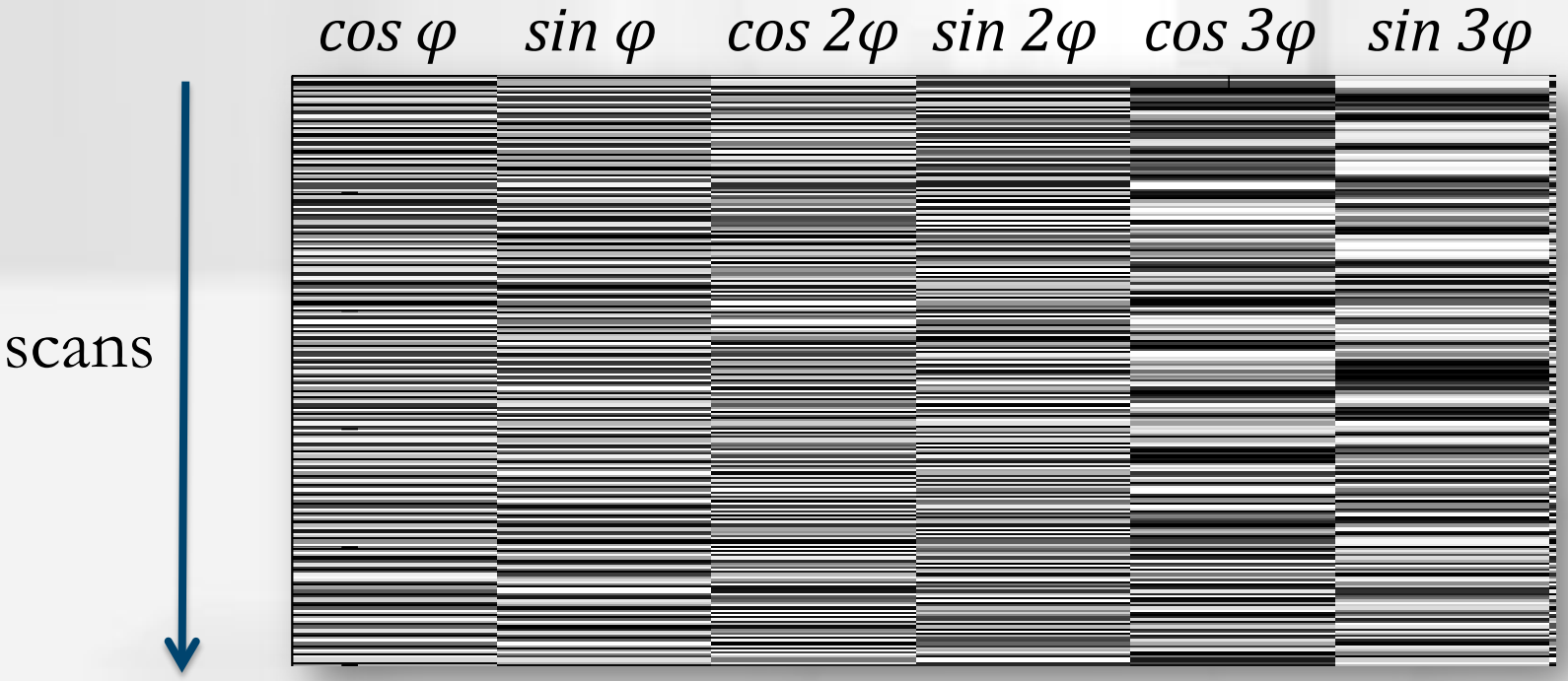
RETROspective Image CORrection

- Cardiac/respiratory phase φ_c φ_r



Noise Modelling: Fourier Phase Expansion

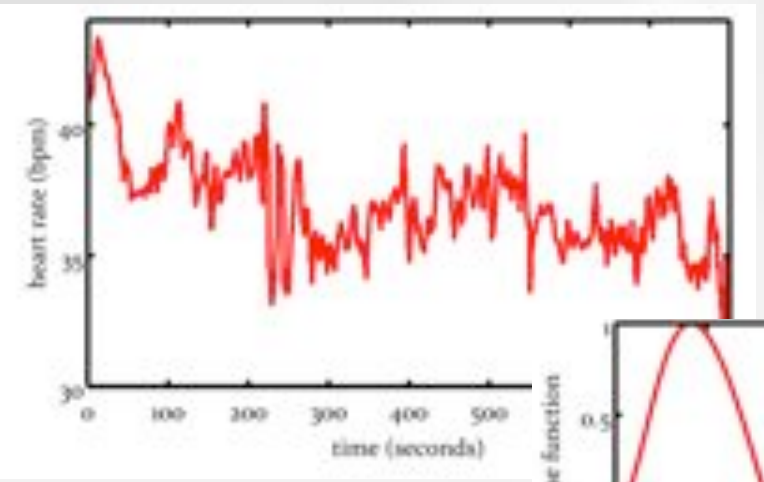
- cosine and sine to allow for constant phase shifts per voxel
- higher model orders to account for under-sampling of physiological frequencies with typical TR in fMRI

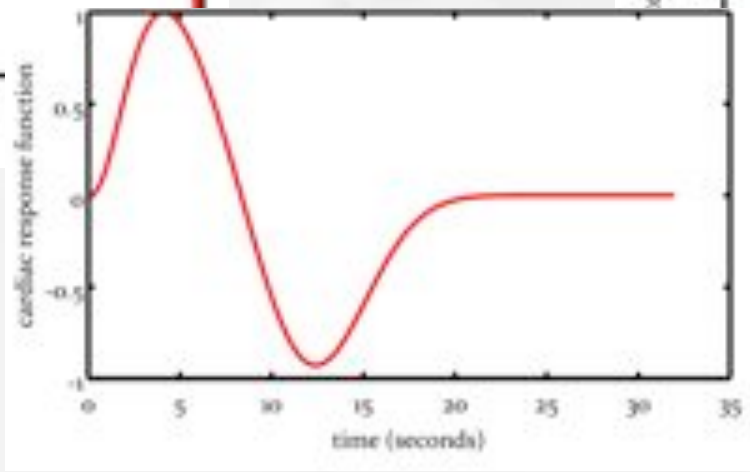


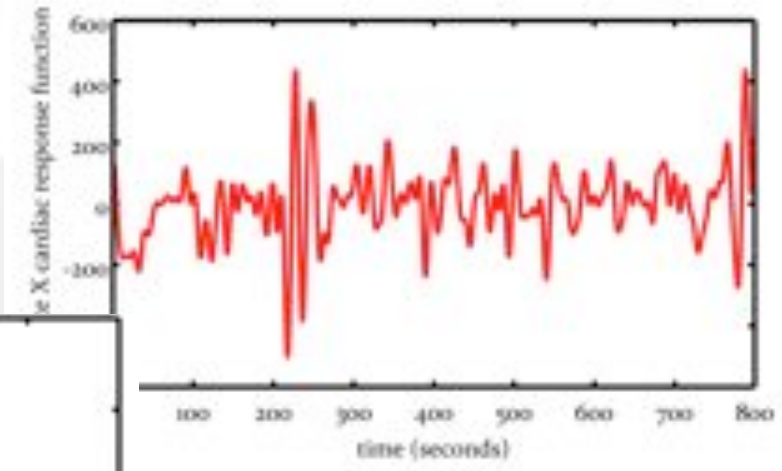
Noise Modelling

RETROspective Image CORrection | **Cardiac Response Function** | Respiratory Response Function

- Heart Rate
- convolved with CRF
- Heart Rate Variability Response Regressor



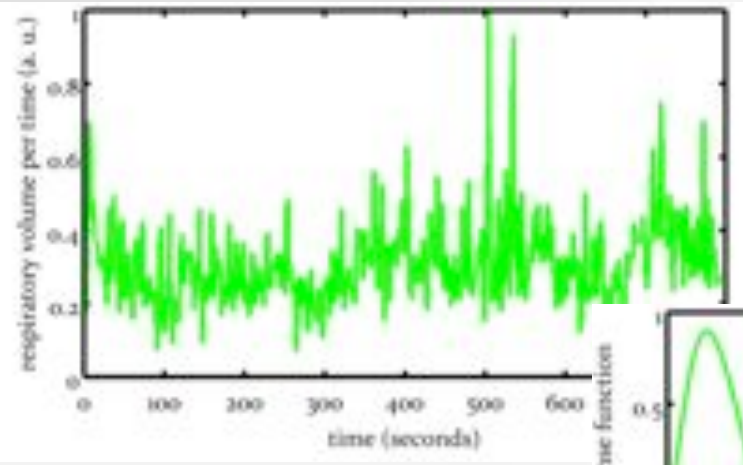


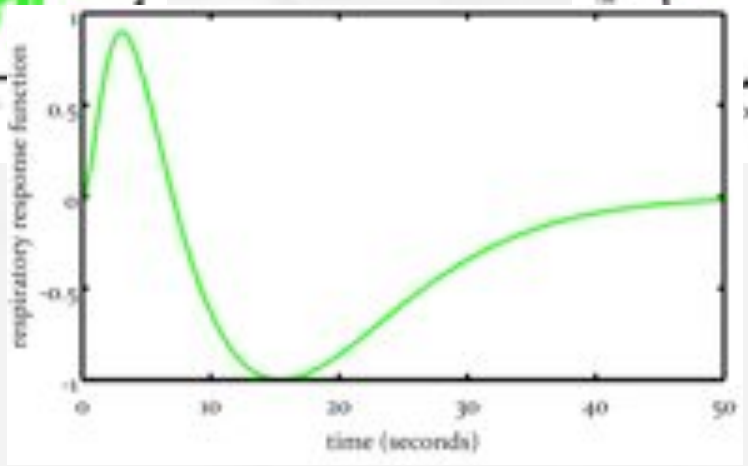


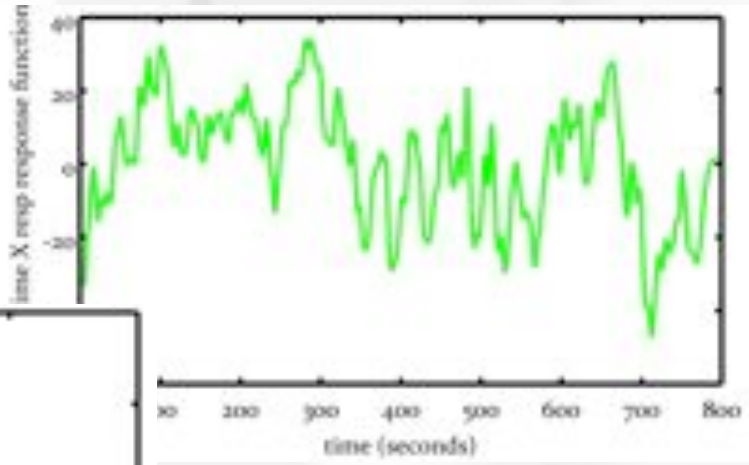
Noise Modelling

RETROspective Image CORrection | Cardiac Response Function | **Respiratory Response Function**

- Respiratory Volume per Time
- convolved with RRF
- Respiratory Volume per Time Regressor







The Solution: Physiological Noise Correction

1. Physiological Monitoring

2. Preprocessing of Physiological Data

3. Model time series physiological noise

4. Noise Reduction and Assessment

Peripheral Devices

PhysIO Toolbox

SPM

ECG, PPU → Cardiac cycle

Breathing belt → Respiratory cycle

Confound regressors

Workflow PhysIO Toolbox

Read logfiles

- Of peripheral physiological data
- Vendor-specific

Preprocess physiological data

- Filter noisy ECG & detect cardiac pulses
- Hand-pick missing pulses

Model time series physiological noise

- RETROICOR
- Respiratory Volume
- Heart Rate

Include confound regressors (GLM)

- Multiple_regressors file for SPM

Finally:

Check Influence of Physiological Noise (Correction) on Data

- SPM
- F-contrast on 1st and second level

Workflow PhysIO Toolbox

Translational Neuromodeling Unit

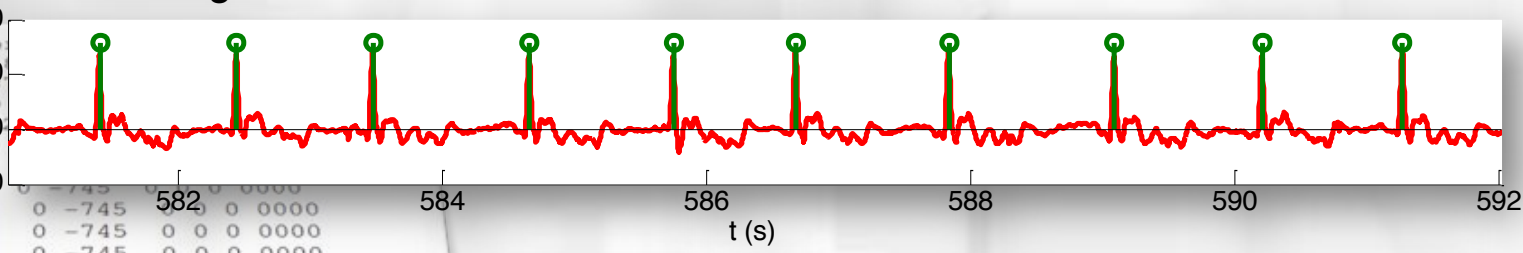
Read logfiles → Preprocess physiological data → Model time series physiological noise → Include confound regressors (GLM)

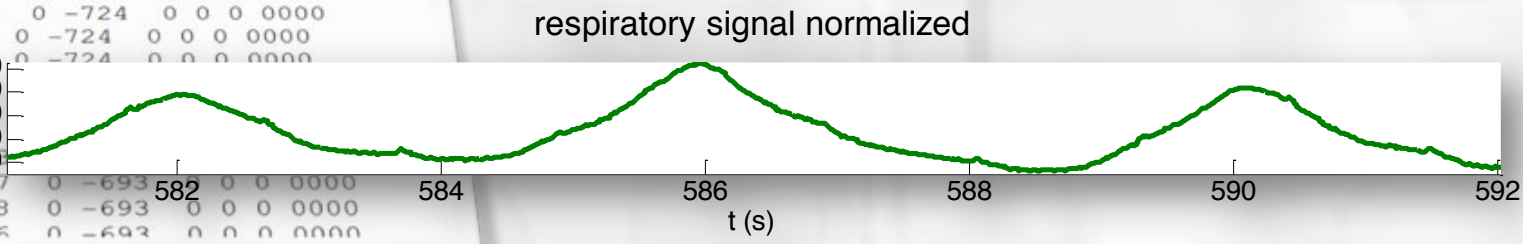
Workflow PhysIO Toolbox

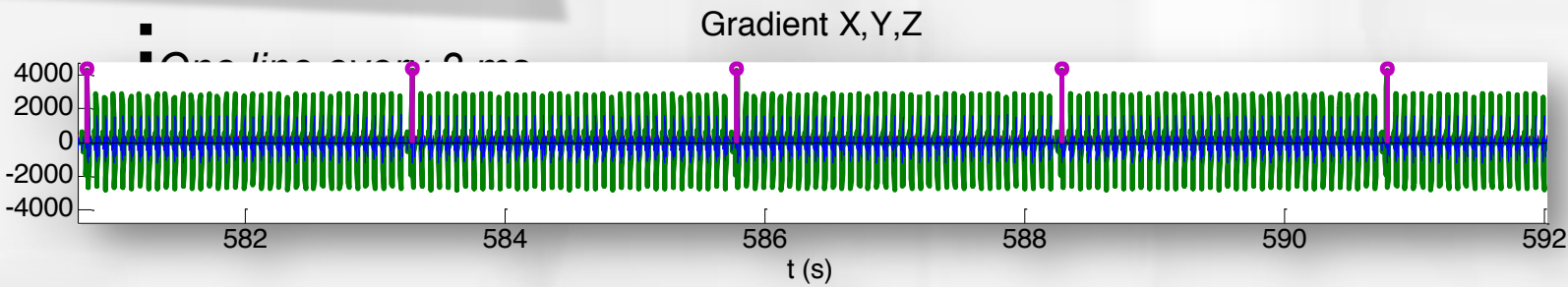
Read logfiles | Preprocess physiological data | Model time series physiological noise | Include confound regressors (GLM)

SCANPHYSLOG.log

```
## Universitaet Zue
## Wed 20-04-20
## 2628 1214 775 38
## Dockable table =
# v1raw v2raw  v1
-458 325  -494 2  0
-497 284  -527 -32
-533 251  -560
-571 219  -592 -104  0 -745  0 0 0000
-606 190  -623 -139  0 -745  0 0 0 0000
-636 159  -653 -173  0 -745  0 0 0 0000
-663 123  -680 -206  0 -724  0 0 0 0000
-688 82  -705 -239  0 -724  0 0 0 0000
-710 36  -726
-724 -9  -744
-733 -50  -758
-736 -85  -767
-737 -116  -771
-736 -145  -770 -457  0 -693  0 0 0 0000
-731 -174  -765 -488  0 -693  0 0 0 0000
-725 -200  -757 -516  0 -693  0 0 0 0000
```



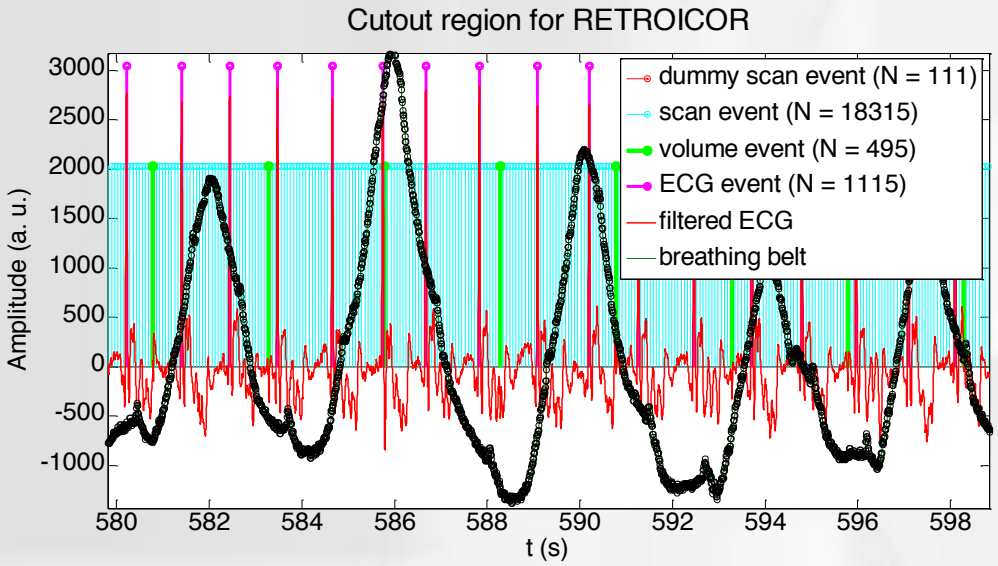




Workflow PhysIO Toolbox

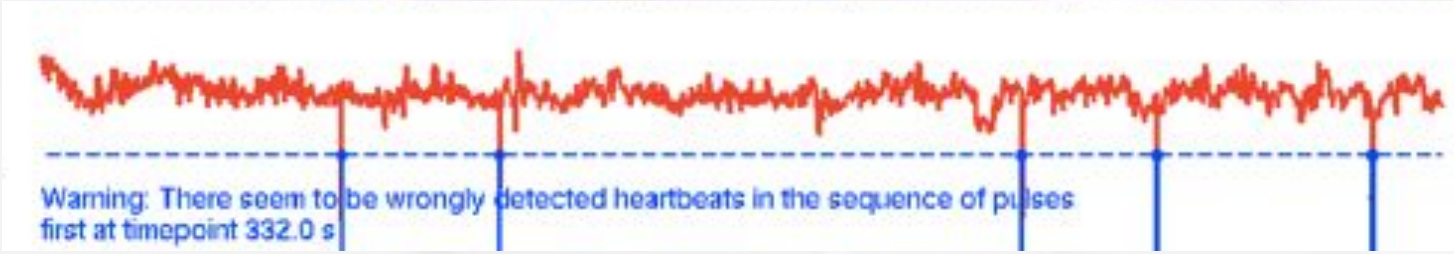
Translational Neuromodeling Unit

Read logfiles | **Preprocess physiological data** | Model time series physiological noise | Include confound regressors (GLM)



- Align scan timing to physiological time series

- Misdetected heartbeats

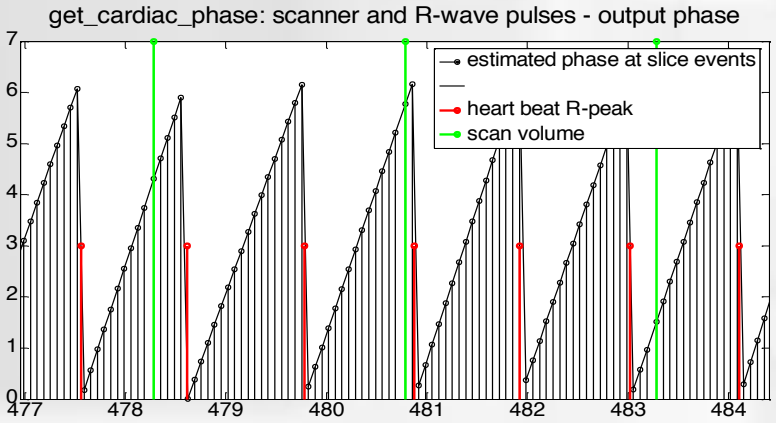


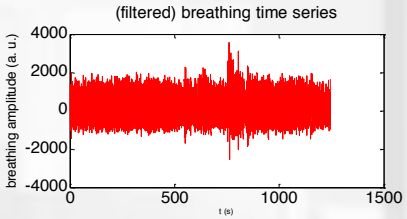
Workflow PhysIO Toolbox

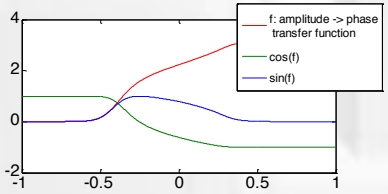
Translational Neuromodeling Unit

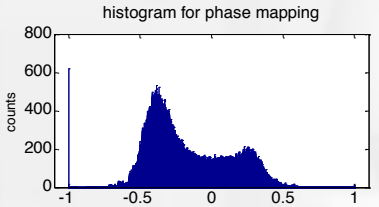
Read logfiles | Preprocess physiological data | **Model time series physiological noise** | Include confound regressors (GLM)

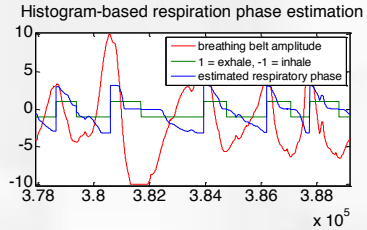
- Cardiac & respiratory phase estimation











- Regressors via Fourier expansion of phases:

  RETROspective Image CORrection (RETROICOR)

Workflow PhysIO Toolbox

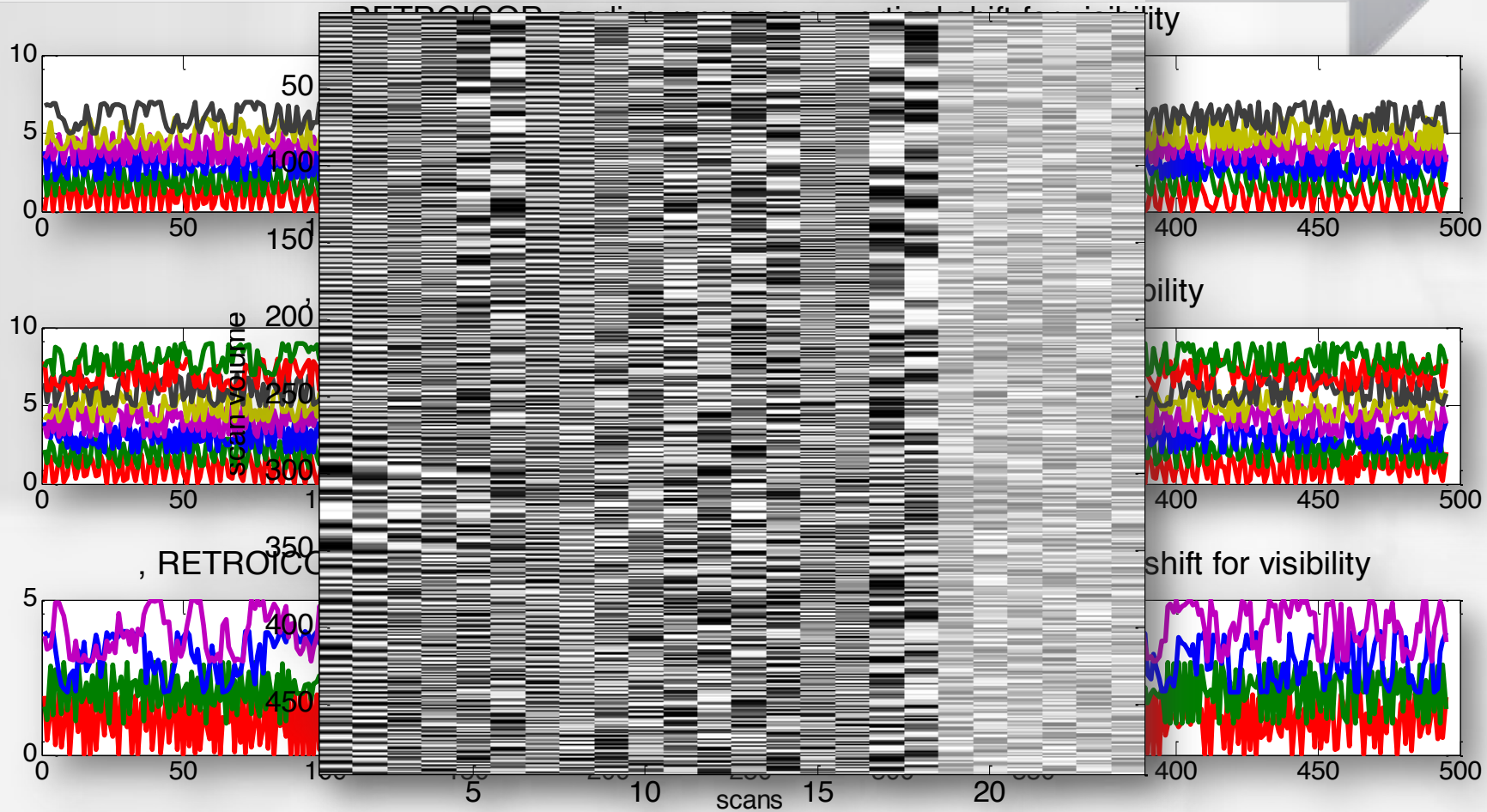
Translational Neuromodeling Unit

Read logfiles

Preprocess physiological data

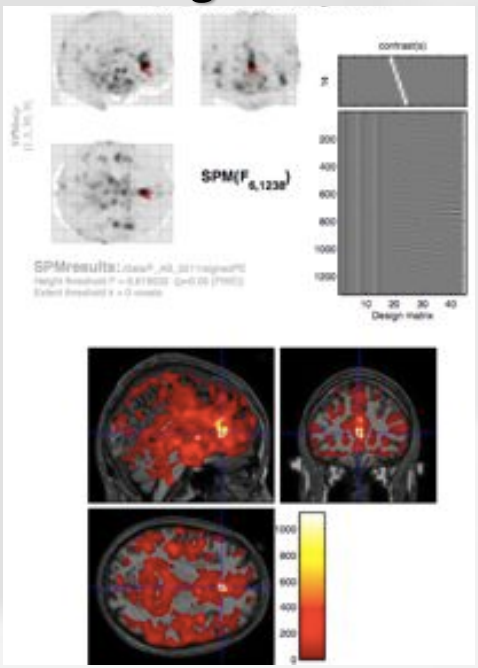
Model time series physiological noise

Include confound regressors (GLM)

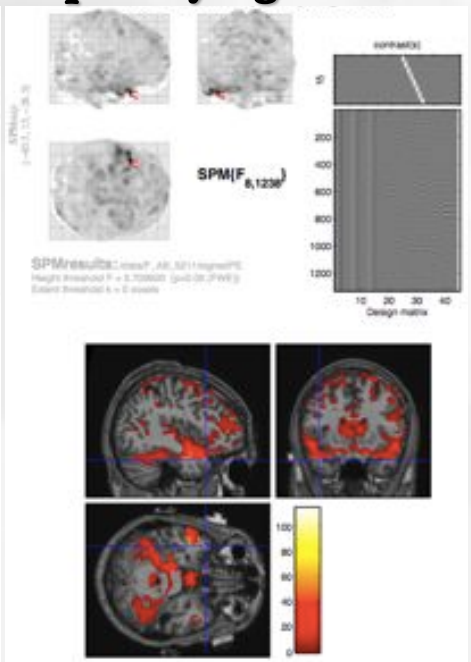


Model Check: SPM F-contrasts

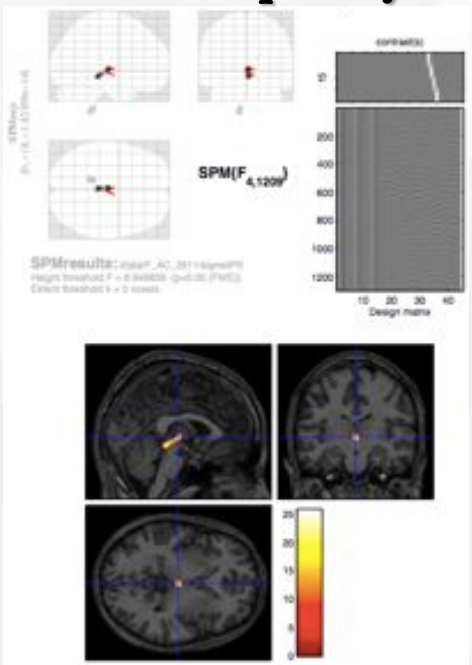
Cardiac regressors



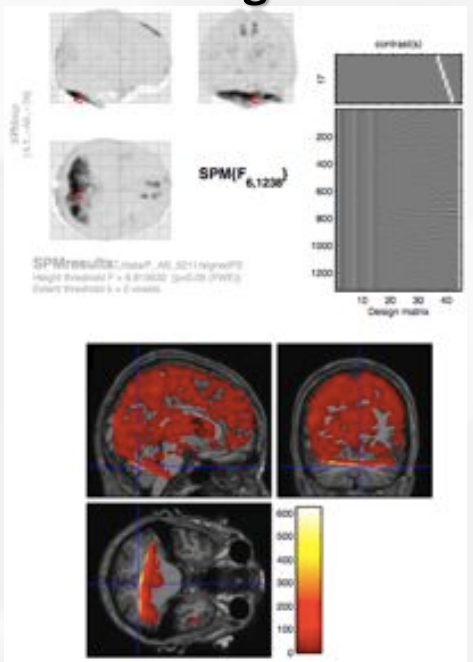
Respiratory regressors



Cardiac x Respiratory



Movement regressors



Finally:

Check Influence of Physiological Noise (Correction) on Data

- SPM
- F-contrast on 1st and second level

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