PHYSIOLOGICAL DE-NOISING FMRI DATA

Katie Dickerson & Jeff MacInnes

February 11th, 2013

OUTLINE

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- Theoretical overview

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- Theoretical overview
- Tutorial in FSL

OVERVIEW

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- Physiological measurements

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- How these signals impact BOLD data

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- Physiological measurements
- How these signals impact BOLD data
- Motivation and importance of removing these signals

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    - averaging data can increase artifact effects (Birn et al., 2009)

PHYSIOLOGICAL MEASURES

Figures from Chang et al., 2009

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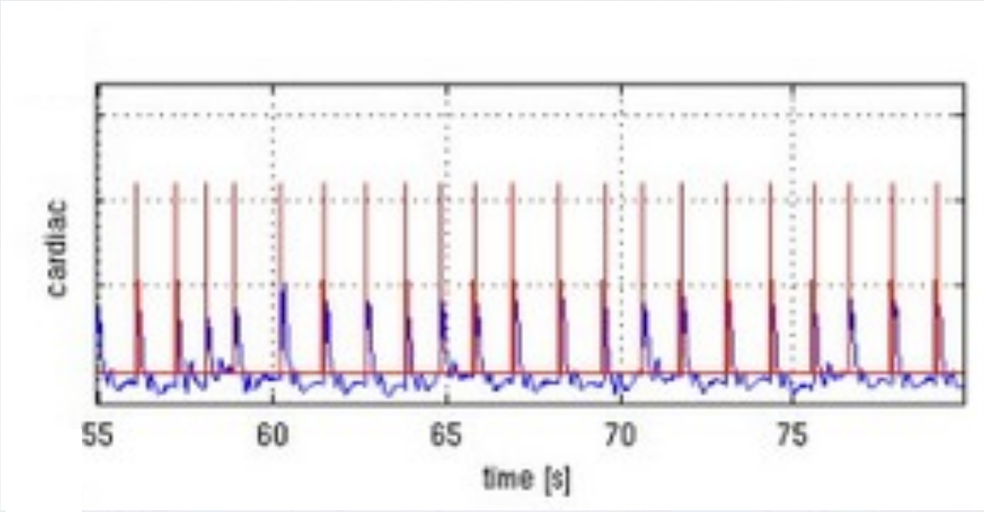

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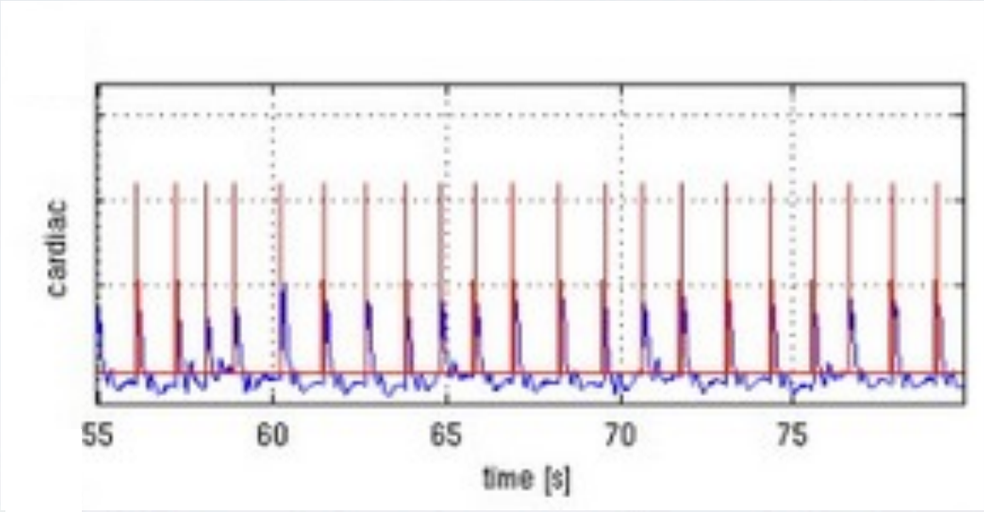

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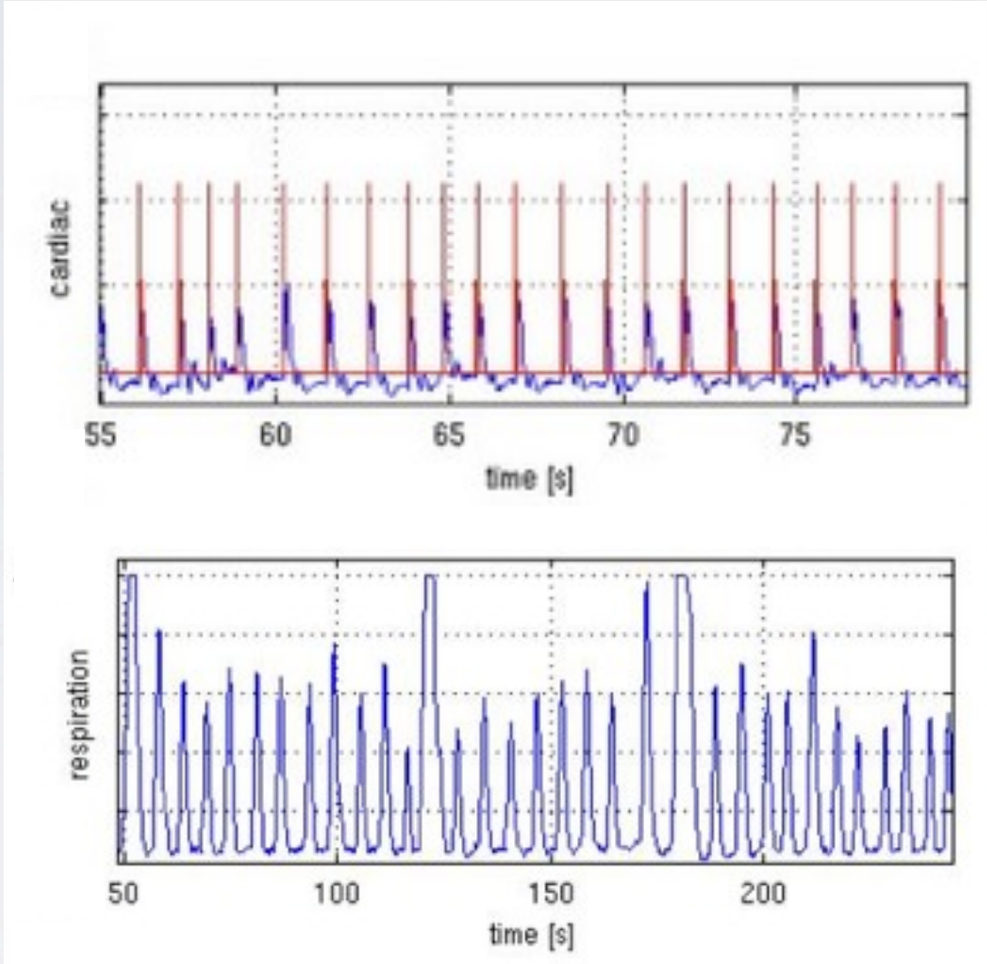

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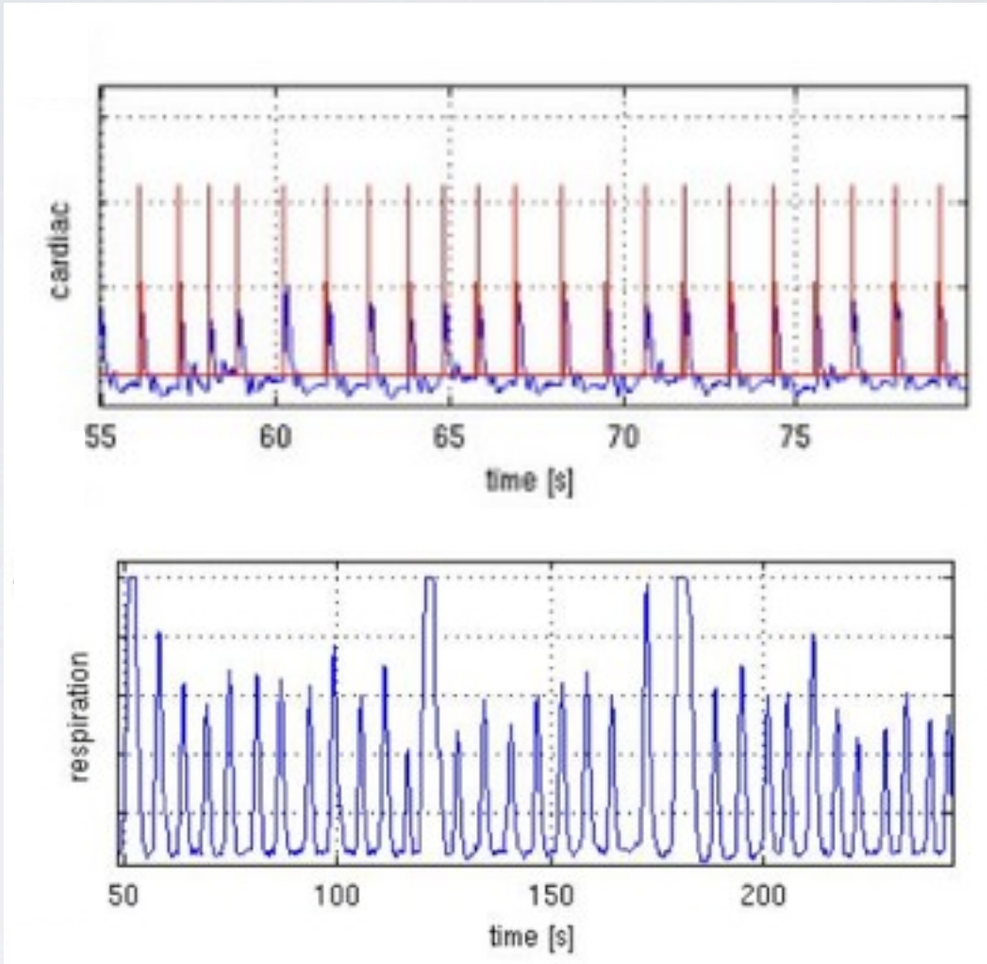

- Respiration

- Respiration volume per time (RVT) - difference between minimum and maximum belt positions at the peaks of inspiration and expiration, divided by the time between the peaks of inspiration (Birn et al., 2006)

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  - global effects (Glover et al., 2000; Birn et al., 2006)

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  - variations in this signal (<0.1 Hz) overlap with frequency range of resting state, functionally connected networks (Cordes et al., 2001; Birn et al., 2006)

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- These add noise which degrades the statistical significance of activation signals

EXAMPLES

CARDIAC INFLUENCES

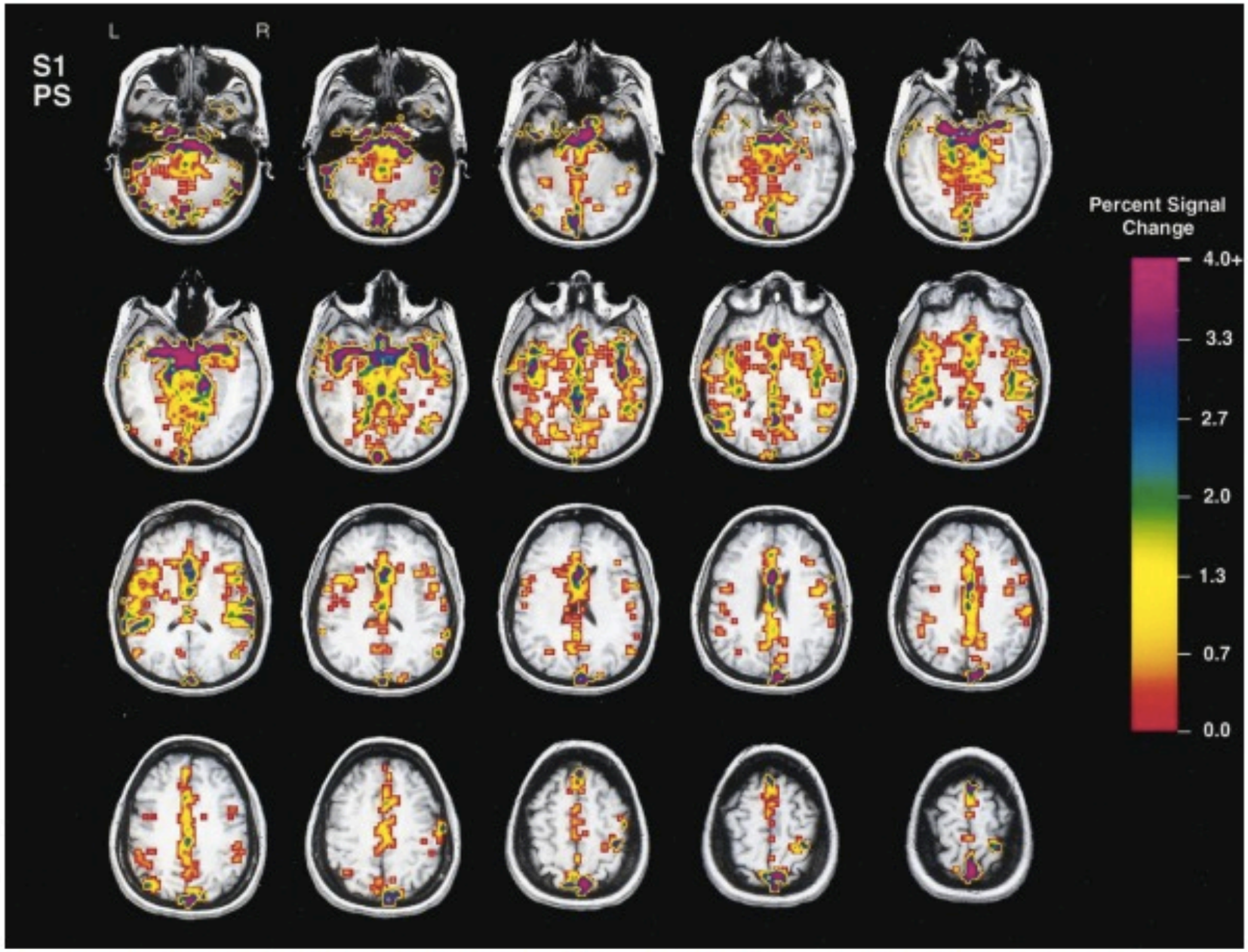

FIG. 2. The full volume of a typical subject showing a topographical display of the percentage signal change during the cardiac cycle. Pixels shown in color indicate regions demonstrating significant cardiac-related signal changes. Overlaid pixel colors have been scaled to reflect percentage signal change according to the color table shown.

Significant effects of cardiac related signal were found in 27.5% of voxels

Figure from Dagli et al., 1999

CARDIAC INFLUENCES

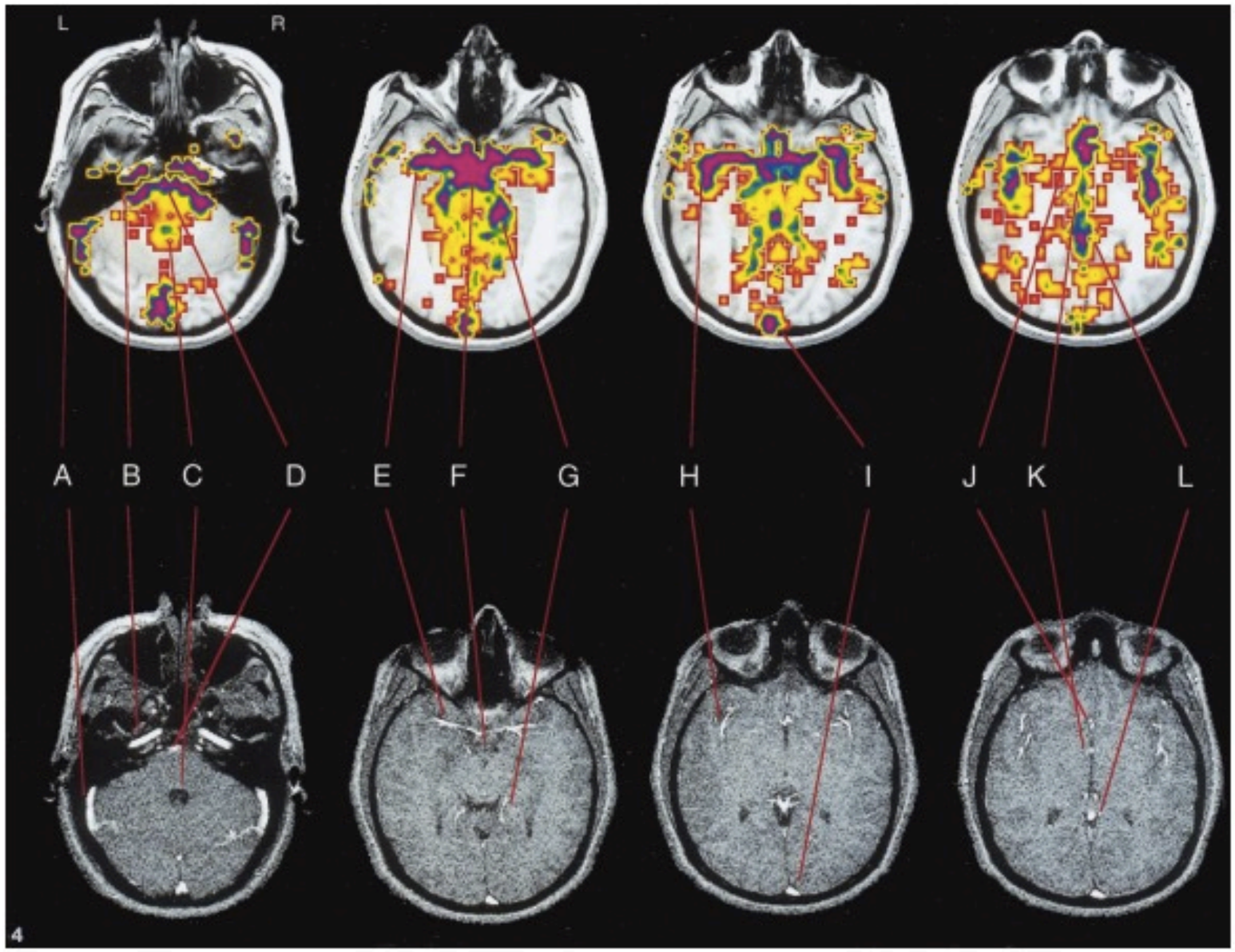

FIG. 4. Comparison of selected functional slices (top slices) from one subject (S1) with the cerebral vasculature as examined by magnetic resonance angiography (bottom slices). The overlaid pixel colors on the functional slices have been scaled to reflect percentage signal change according to the color table shown in Fig. 2. There is a strong correspondence of tissue areas showing significant cardiac-related signal change to the locations of major blood vessels and CSF pools (A—transverse sinus, B—carotid artery, C—fourth ventricle, D—basilar artery, E—main trunk of middle cerebral artery (MCA), F—circle of Willis (entire region), G—posterior cerebral artery, H—branch of MCA, I—superior sagittal sinus, J—anterior cerebral artery, K—third ventricle, L—inferior sagittal sinus).

Figure from Dagli et al., 1999

RESPIRATION INFLUENCES

- RVT & resting state functional connectivity - overlapping networks

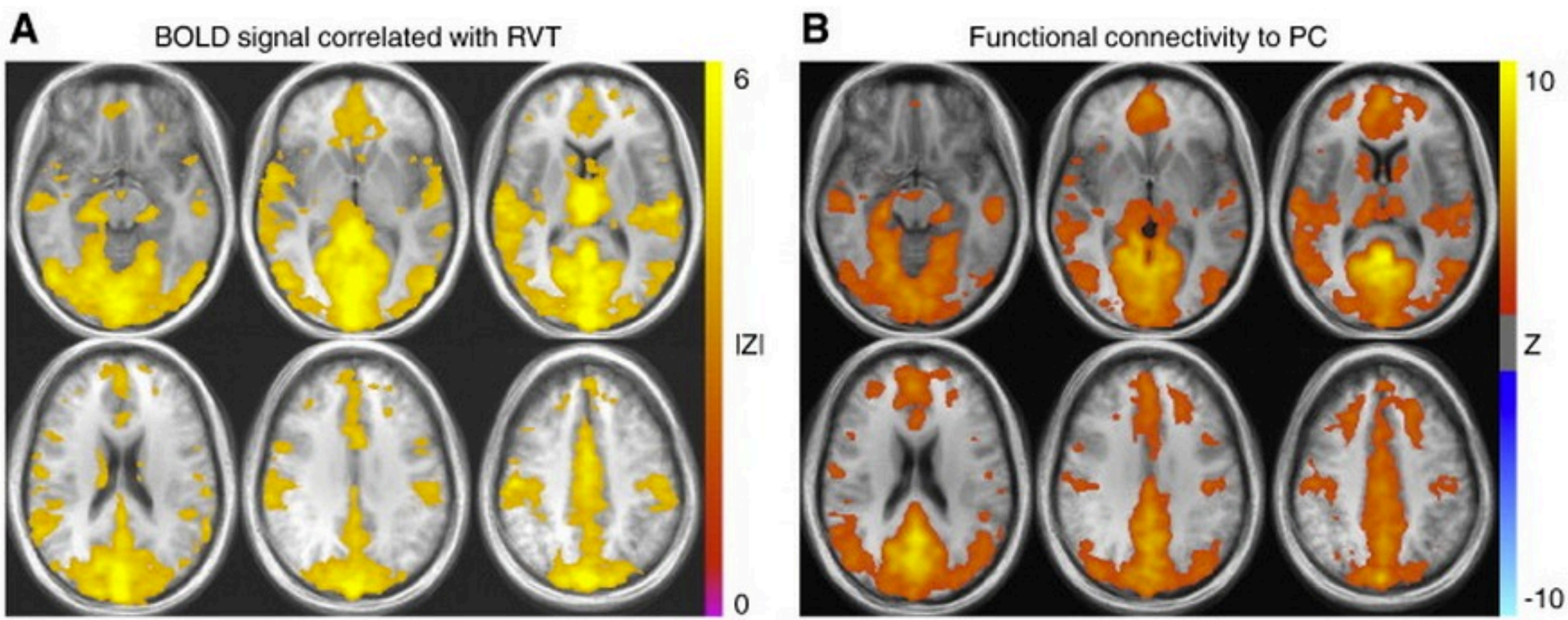

Fig. 2. A) fMRI signal correlated with respiration volume per time (RVT) changes, B) functional connectivity with a seed region in the posterior cingulate from a group of 10 subjects.

Figure from Birn 2012

RESPIRATION INFLUENCES

- RVT & functional data

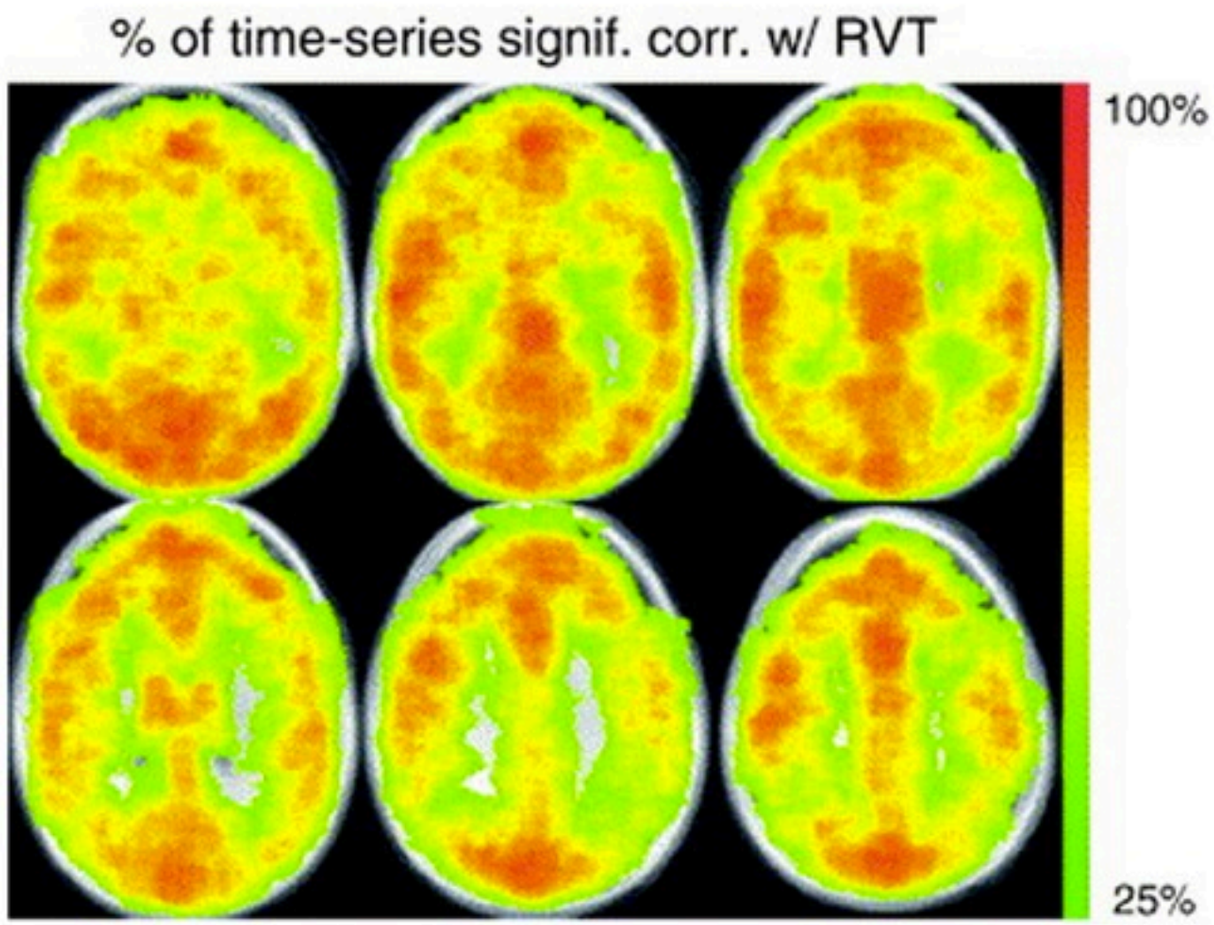

Fig. 2. Location of respiration changes: map showing for each voxel the percentage of time series (out of a total of 16 runs from 10 subjects) where the fMRI signal during rest was significantly (CC > 0.4, $P < 10^{-6}$ uncorrected) correlated with the respiration volume per time (RVT) changes. Signal changes are largest in gray matter and near large blood vessels.

Figure from Birn et al., 2006

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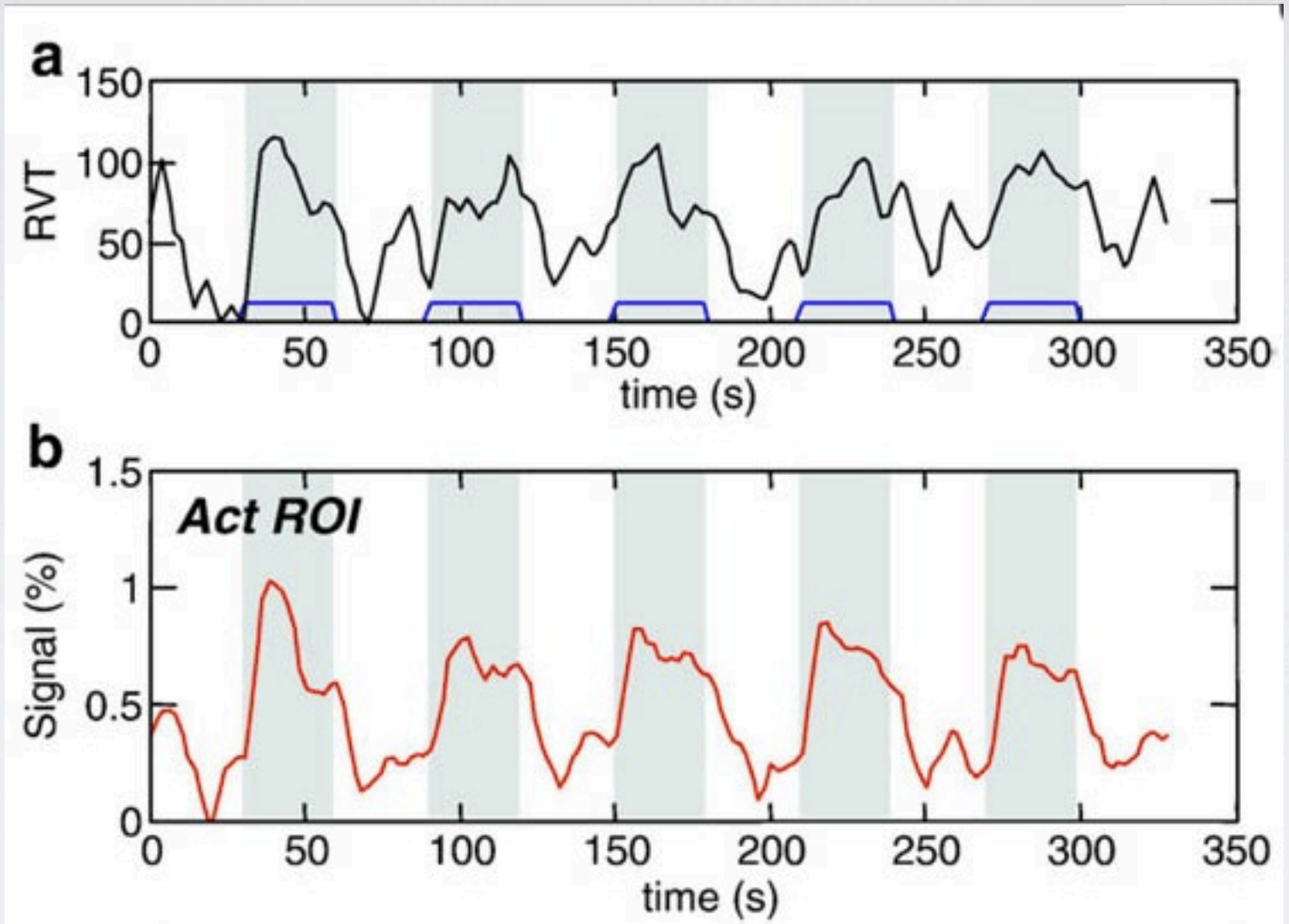

(a) Time course of respiration volume per time during the lexical task averaged over all subjects. Bottom 4 graphs show signal intensity time courses averaged over all subjects and over different regions of interest: regions with significant (b) activation, (c) de-activation (relative to resting baseline), (d) RVT changes, and (e) RVT changes outside of regions showing lexical activations or deactivations. Times during which the lexical task was performed are indicated in gray.

Figure from Birn et al., 2009

CORRECTING PHYSIOLOGICAL NOISE

IDENTIFYING PHYSIO SIGNALS

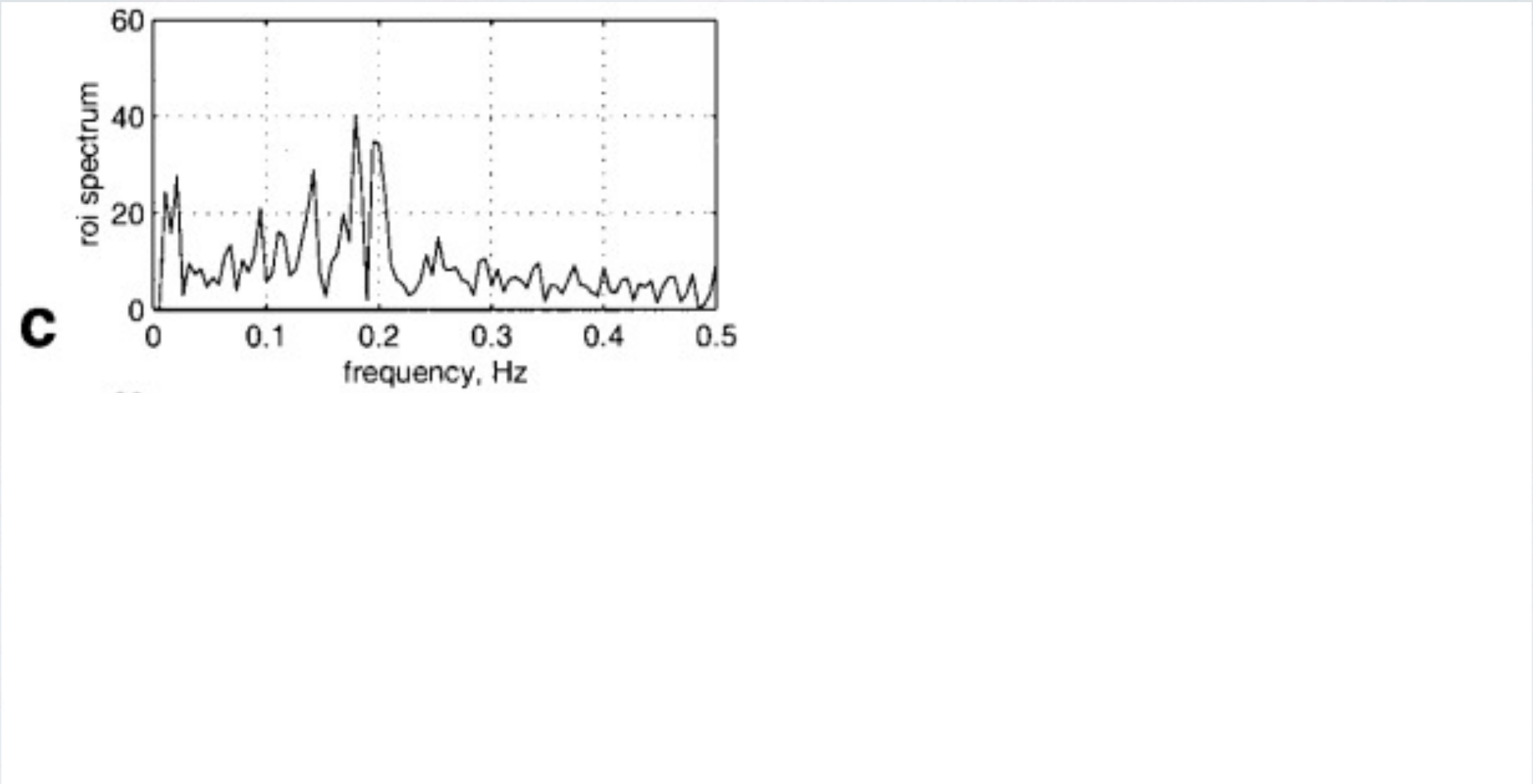

Figure from Glover et al., 2000

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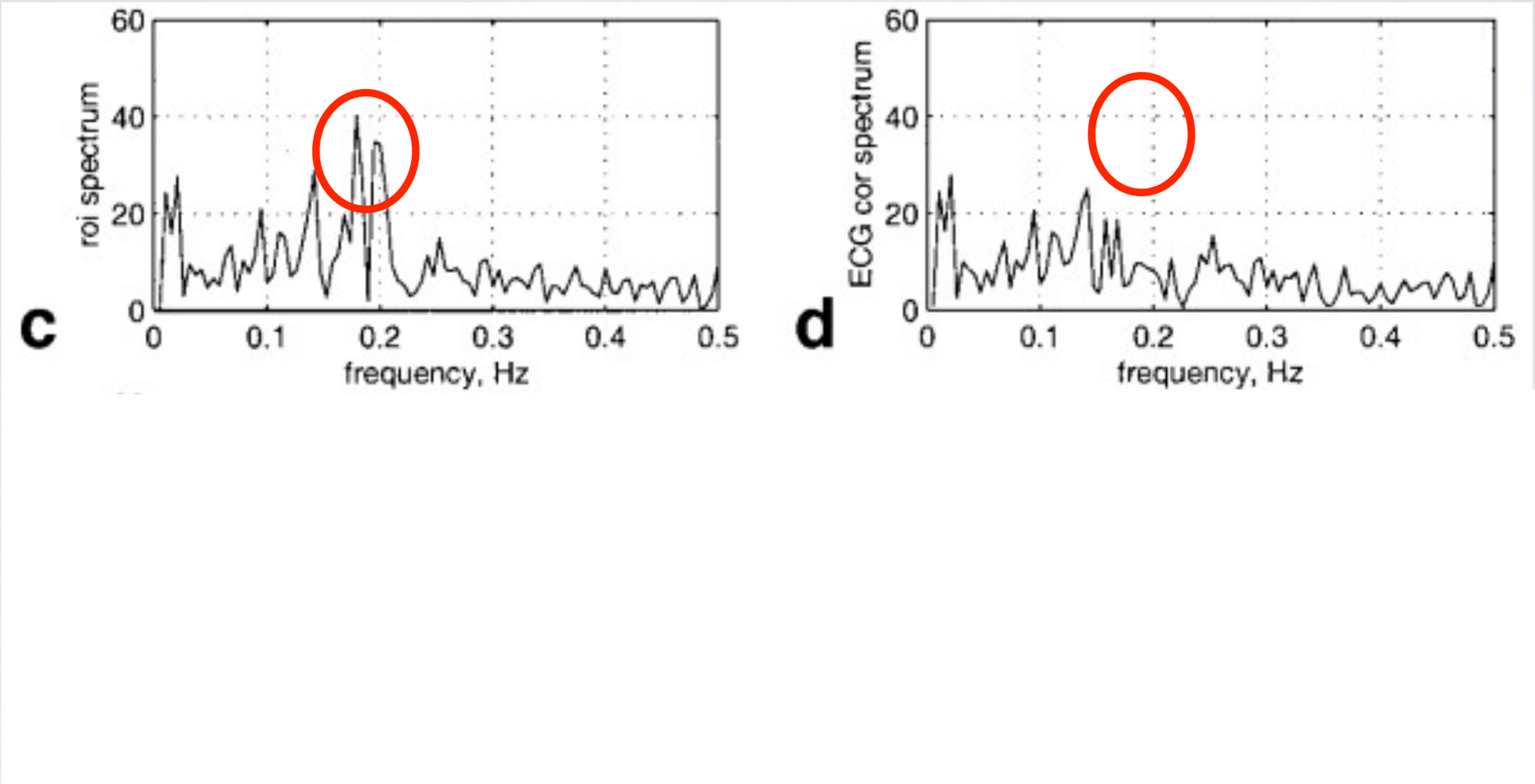

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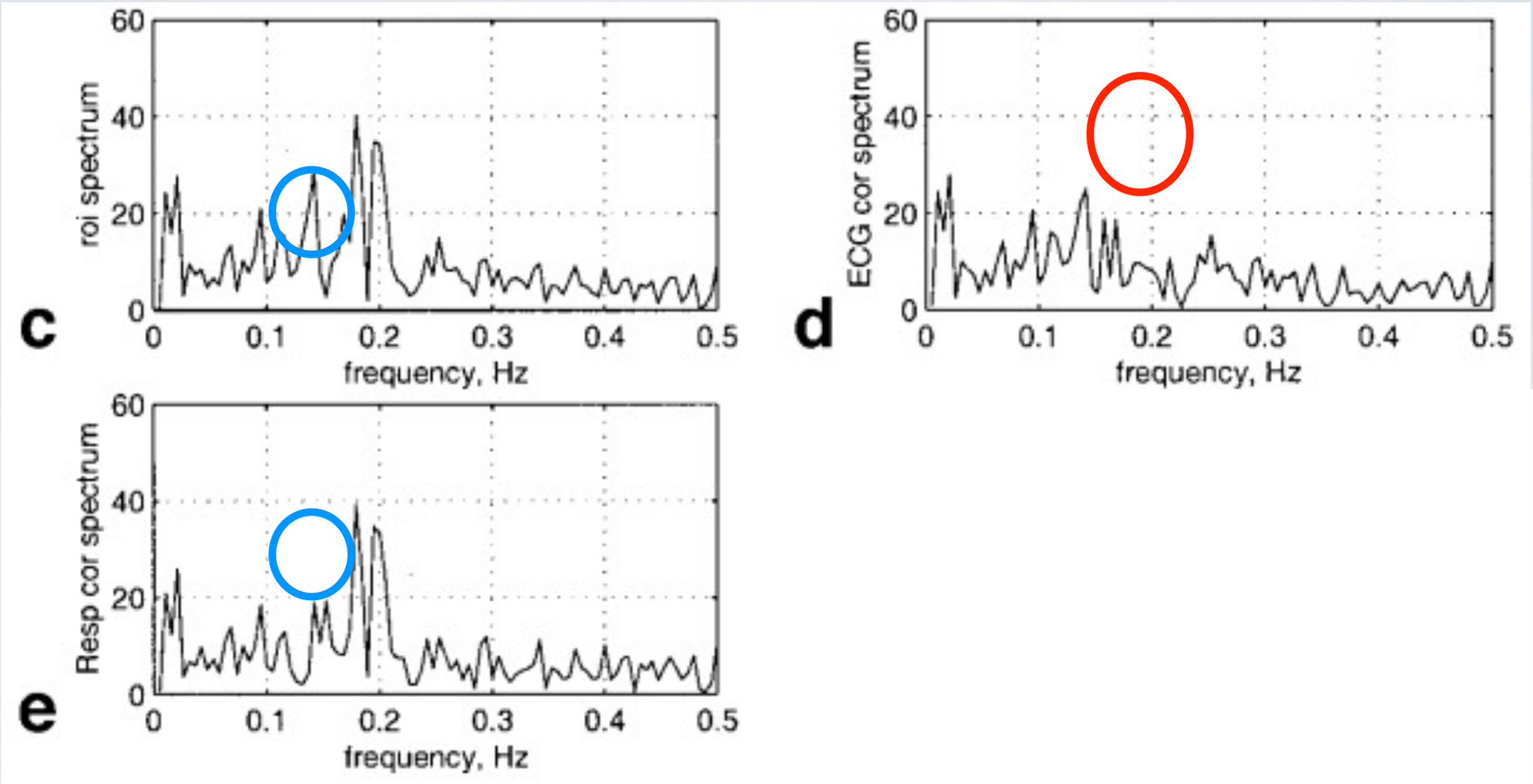

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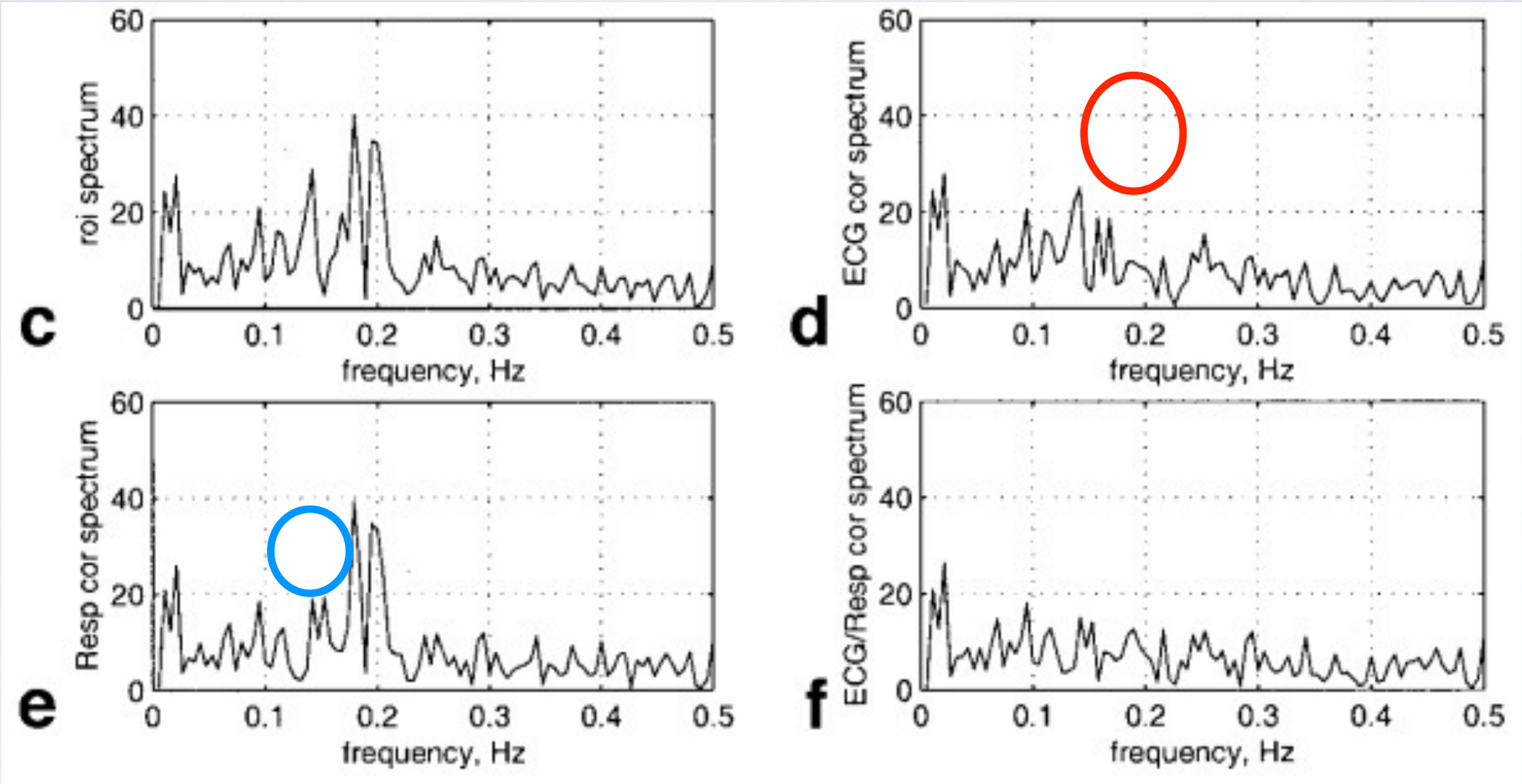

Figure from Glover et al., 2000

CORRECTION REDUCES STDEV

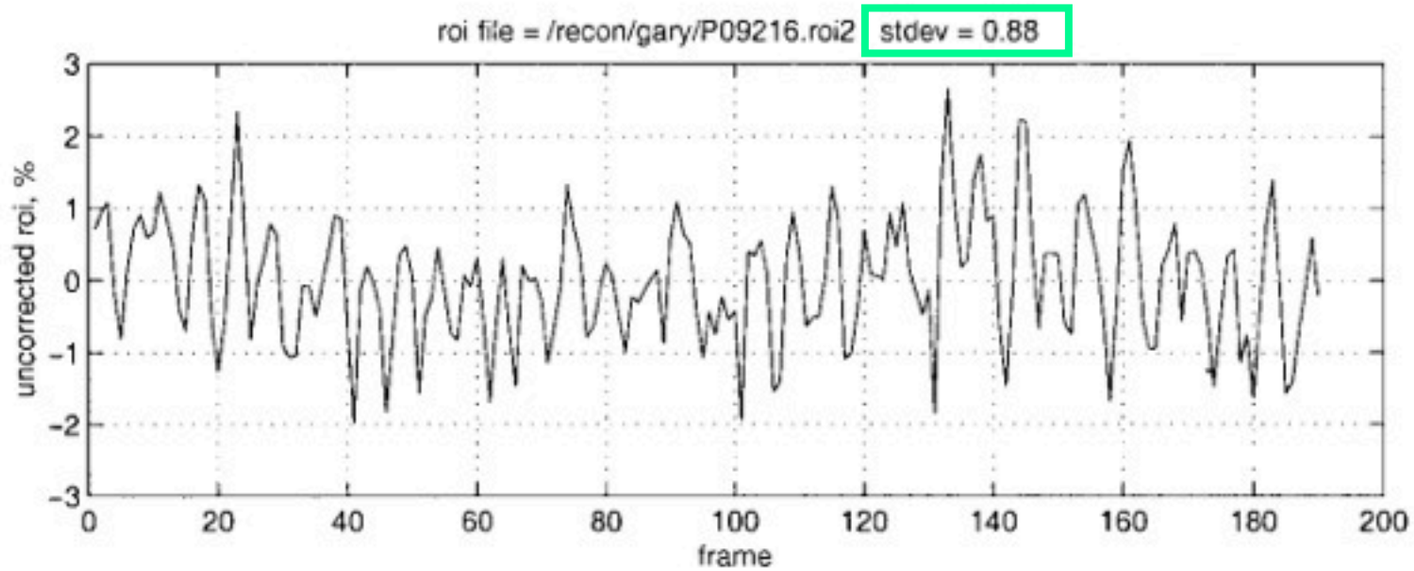

FIG. 2. Time series without (**top**) and with (**bottom**) RETROICOR correction corresponding to Fig. 1. Ordinate values are expressed as percentage of mean values.

Figure from Glover et al., 2000

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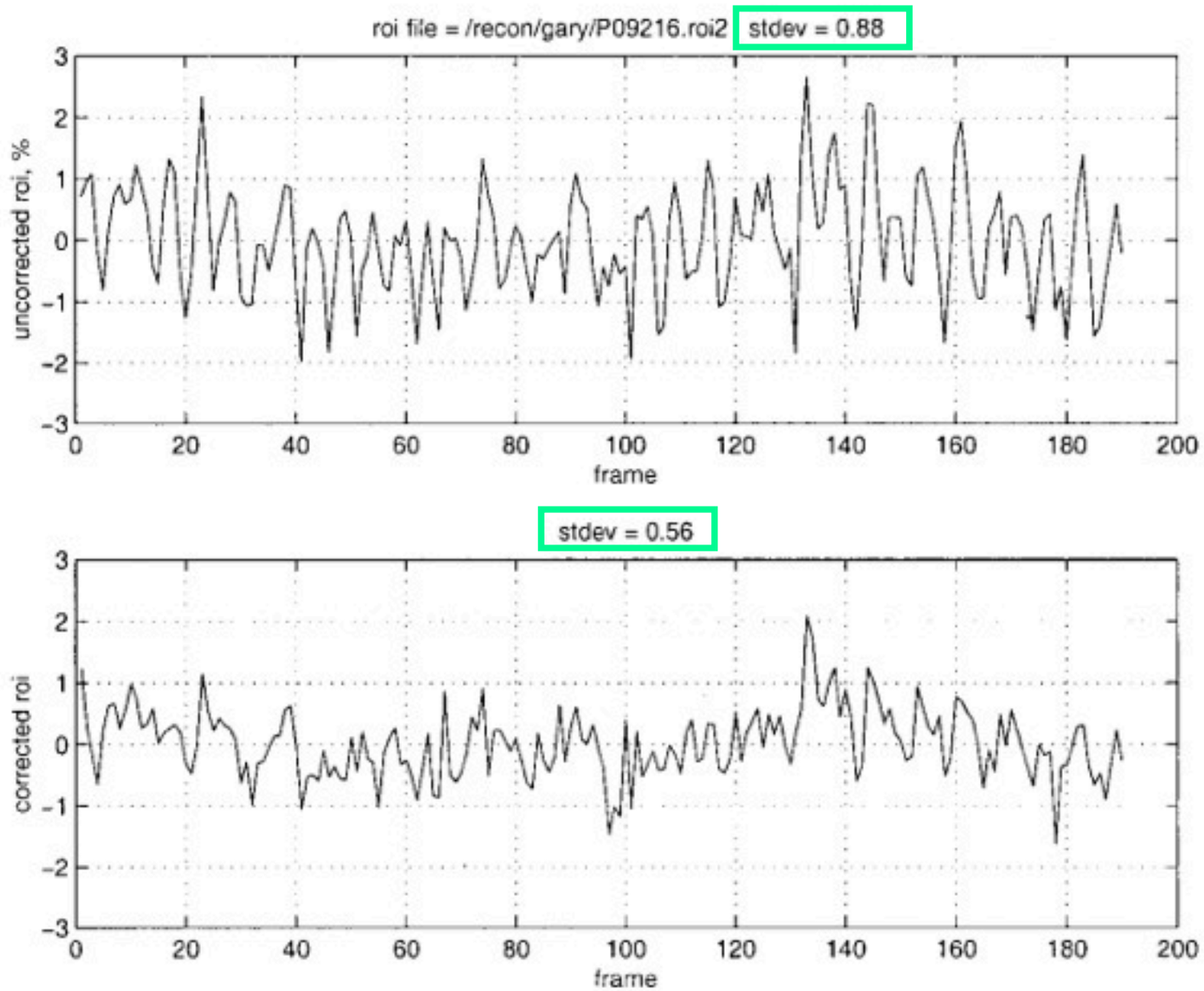

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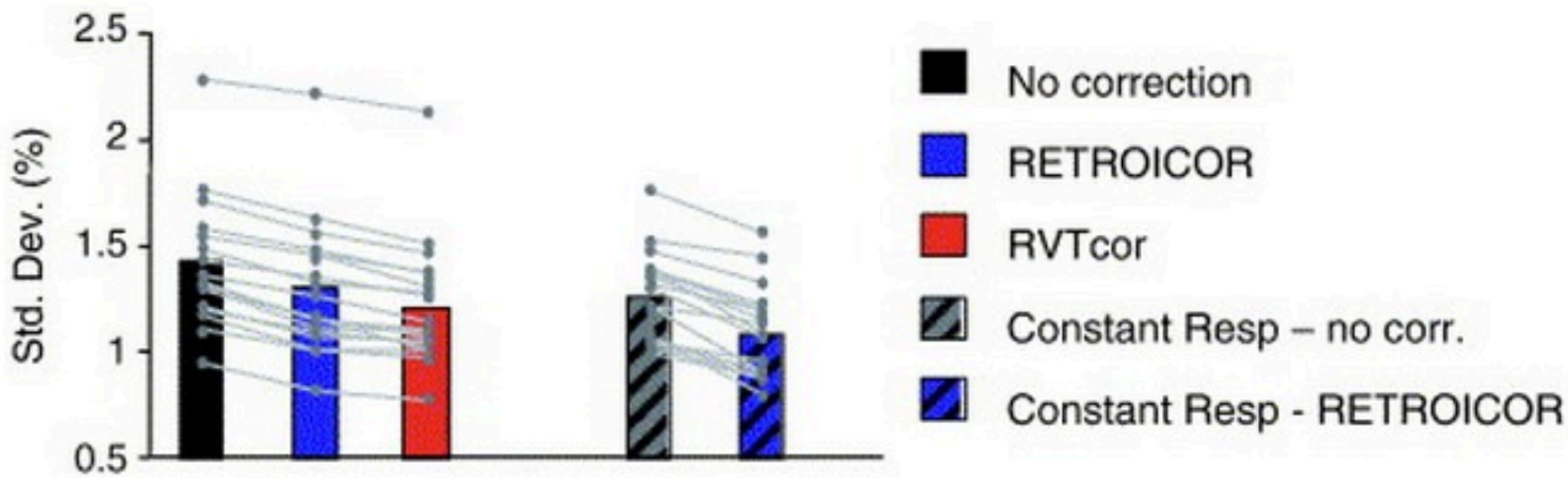

Fig. 5. Standard deviation: average temporal standard deviation without correction, with RETROICOR correction, respiration volume per time correction (RVTcor), constant respirations, and constant respirations with RETROICOR. Lines indicate temporal standard deviation for each subject, averaged over the whole brain. Bar graph indicates average over all subjects.

Figure from Birn et al., 2006

CORRECTION IMPROVES DETECTION

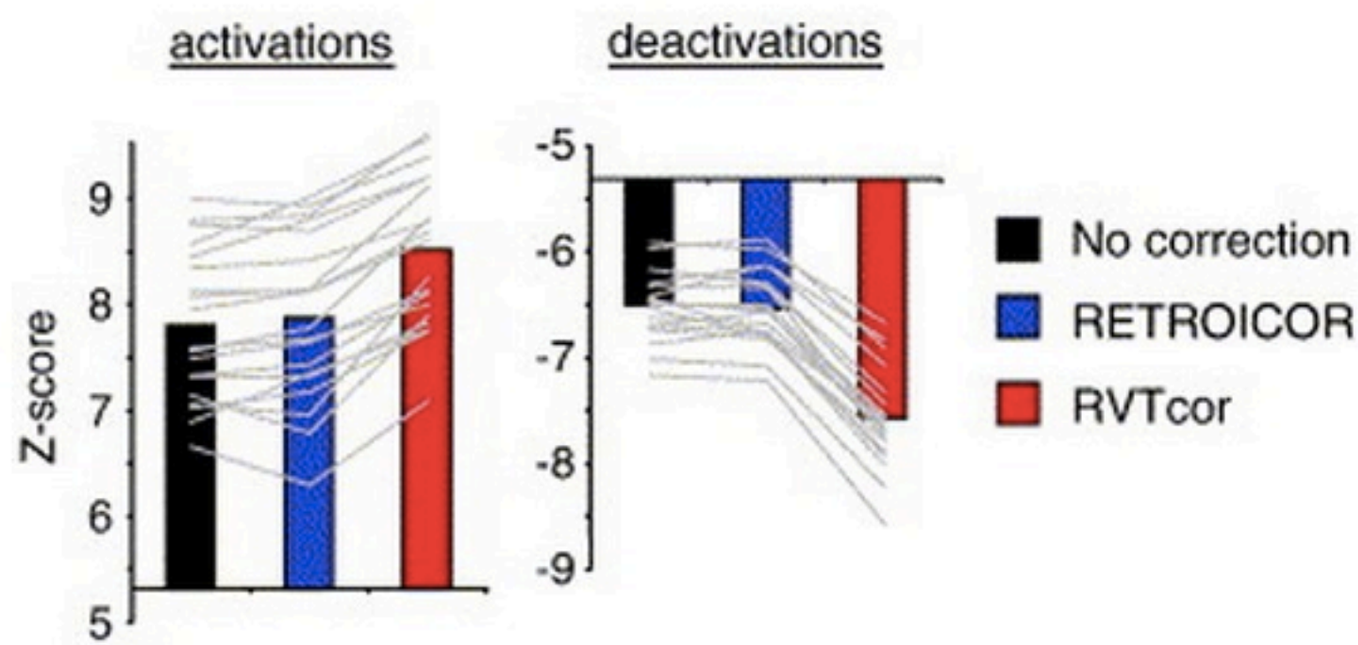

Fig. 9. Detection of (de-)activation: Average *Z* scores for regions positively ("activations") and negatively ("deactivations") correlated with the lexical task without correction, with RETROICOR correction, and with respiration volume per time correction (RVTcor).

Figure from Birn et al., 2006

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  - ICA - identify and remove fluctuations that match patterns of known physiological noise (Perlbag et al., 2007; Beall and Lowe, 2007)
    - Caveat: cannot validate signal you identify is due to physiological measures

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TUTORIAL IN FSL

physio recording

physiological data acquisition while scanning at BIAC

data formatting

formatting acquired data for subsequent analyses

physio noise modeling

physiological denoising as implemented in FSL 5.0

physio recording

easy to record physiological measures from within PTB/matlab experiment script

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recordPhysio.m

recording step	code snippet
initialize analog input device	`m = recordPhysio('init')`
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BIAC 5 analog channels

default channels for recordPhysio.m in **bold**

channel	input signal
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4	Biopac Cardiac (oxSat)
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for up-to-date channel info:

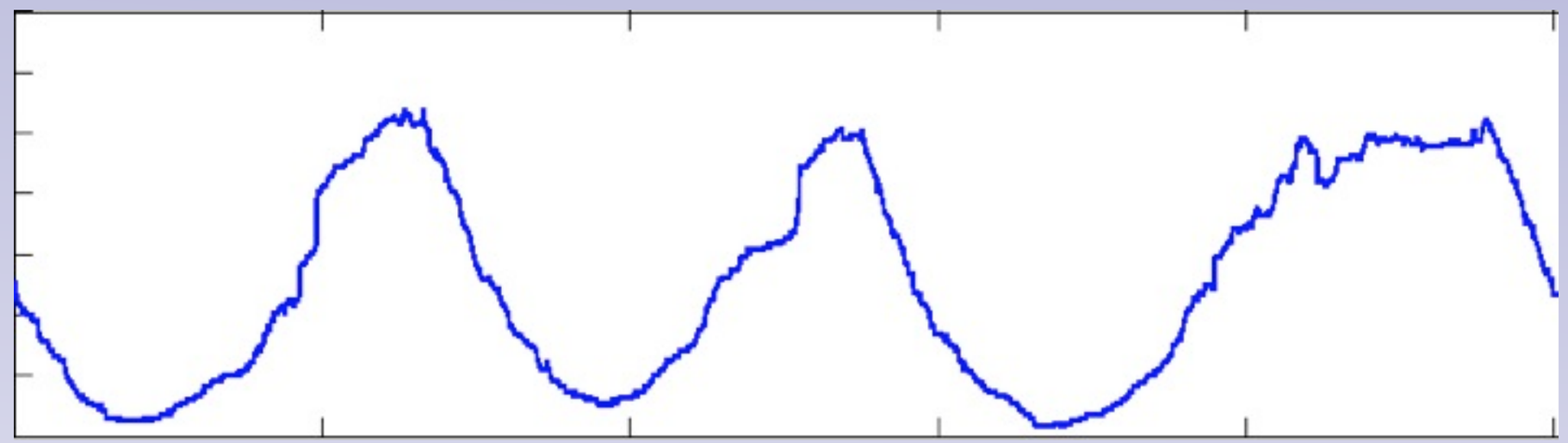
BIAC 5 info:
http://wiki.biac.duke.edu/biac:experimentalcontrol:biac5hardware

BIAC 6 info:
http://wiki.biac.duke.edu/biac:experimentalcontrol:biac6hardware

physio recording

example raw signals

respiration



10s

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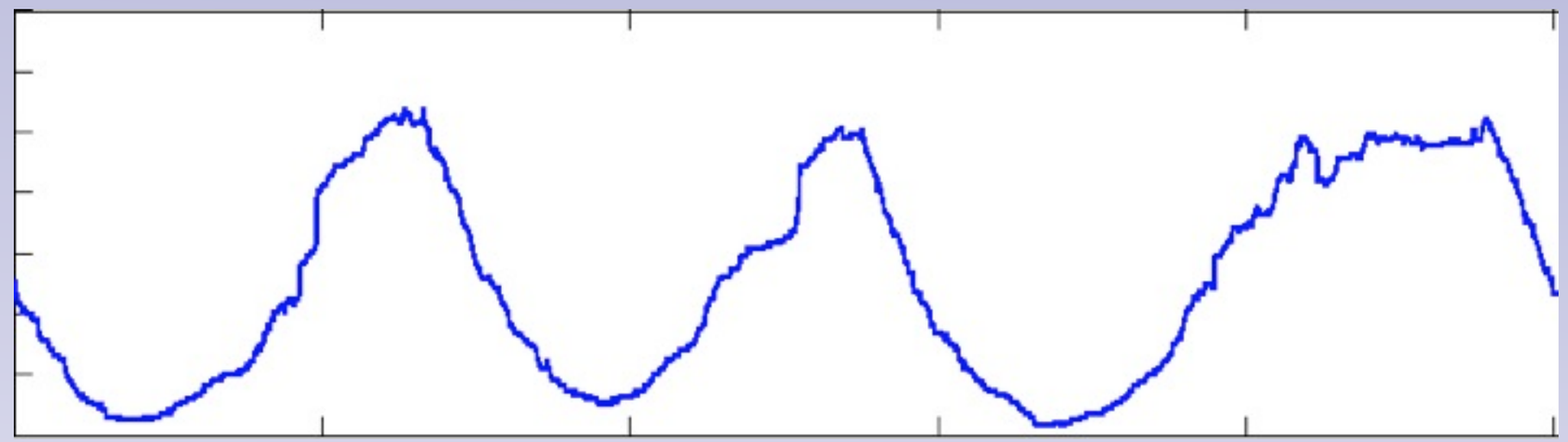
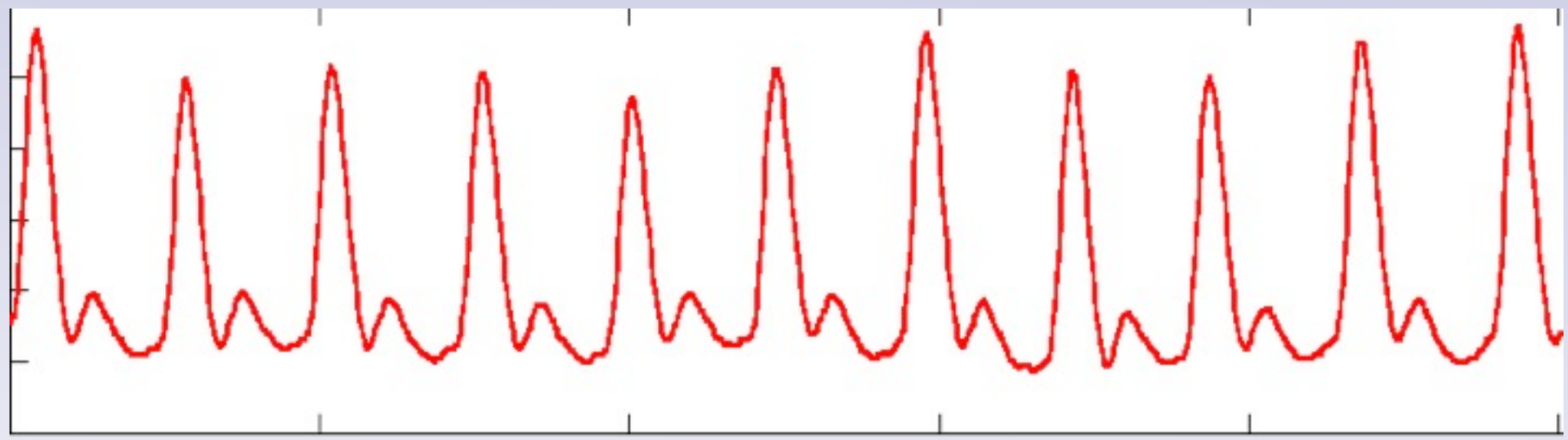


cardiac



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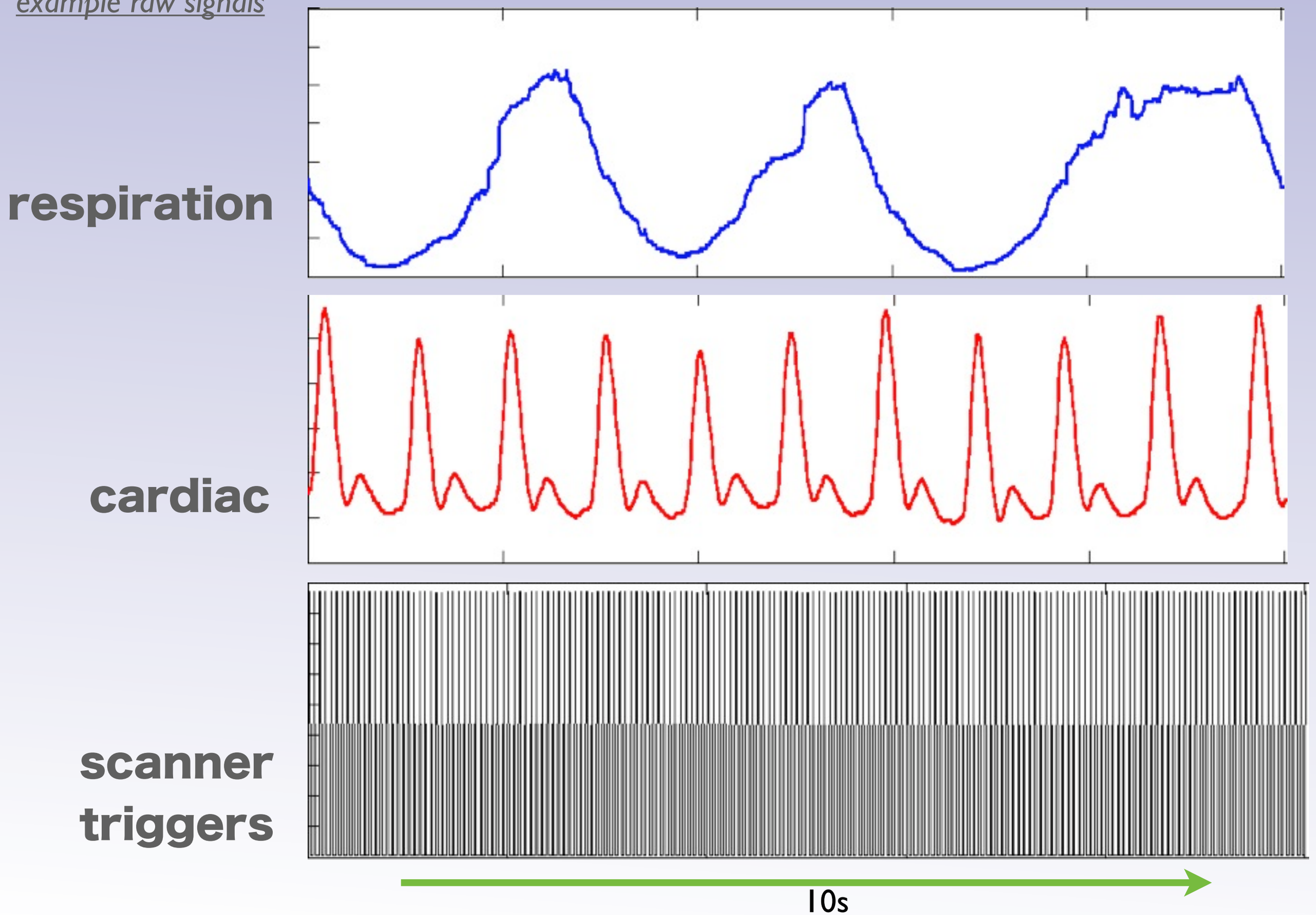

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fsl

PNM tools

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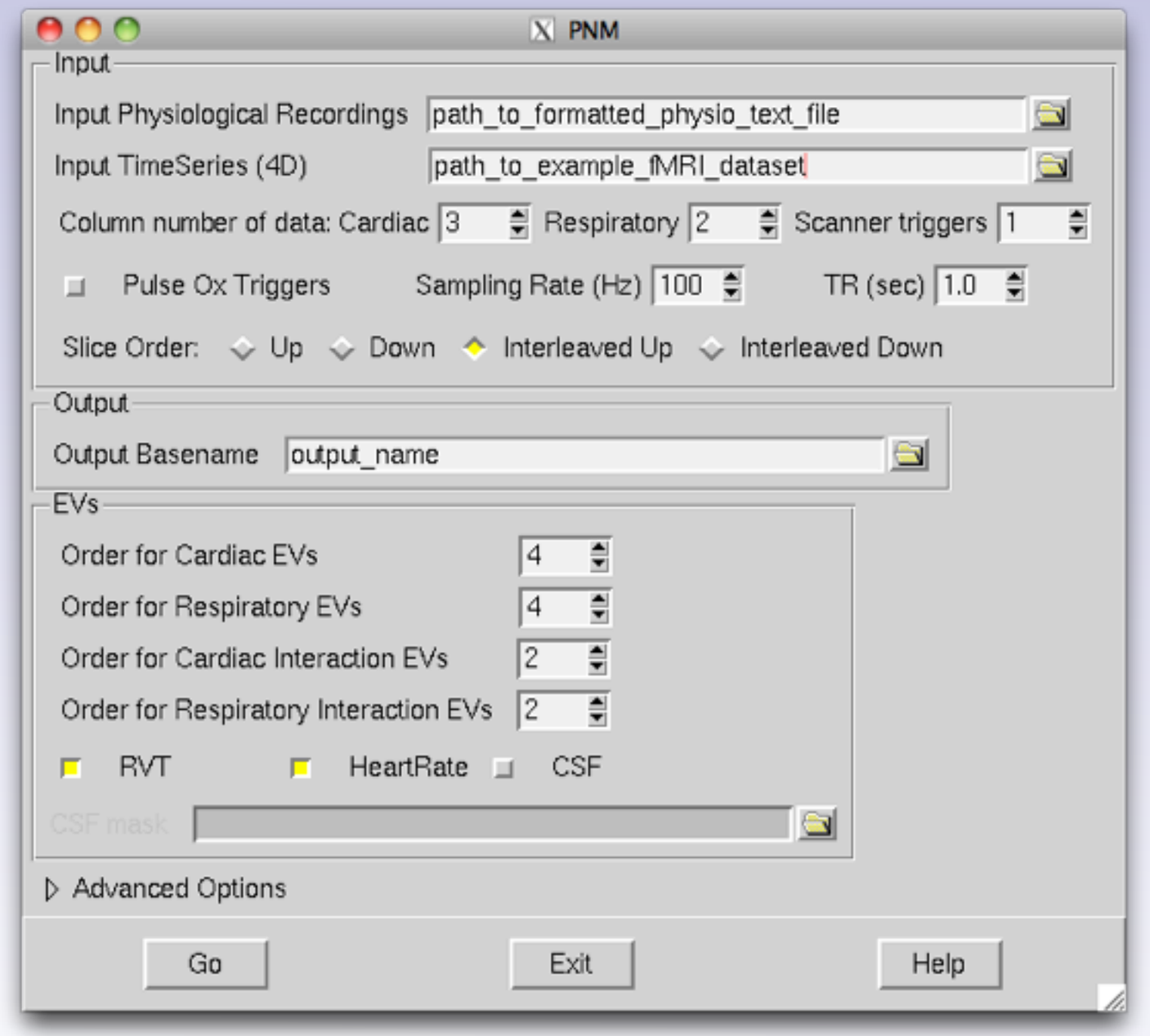

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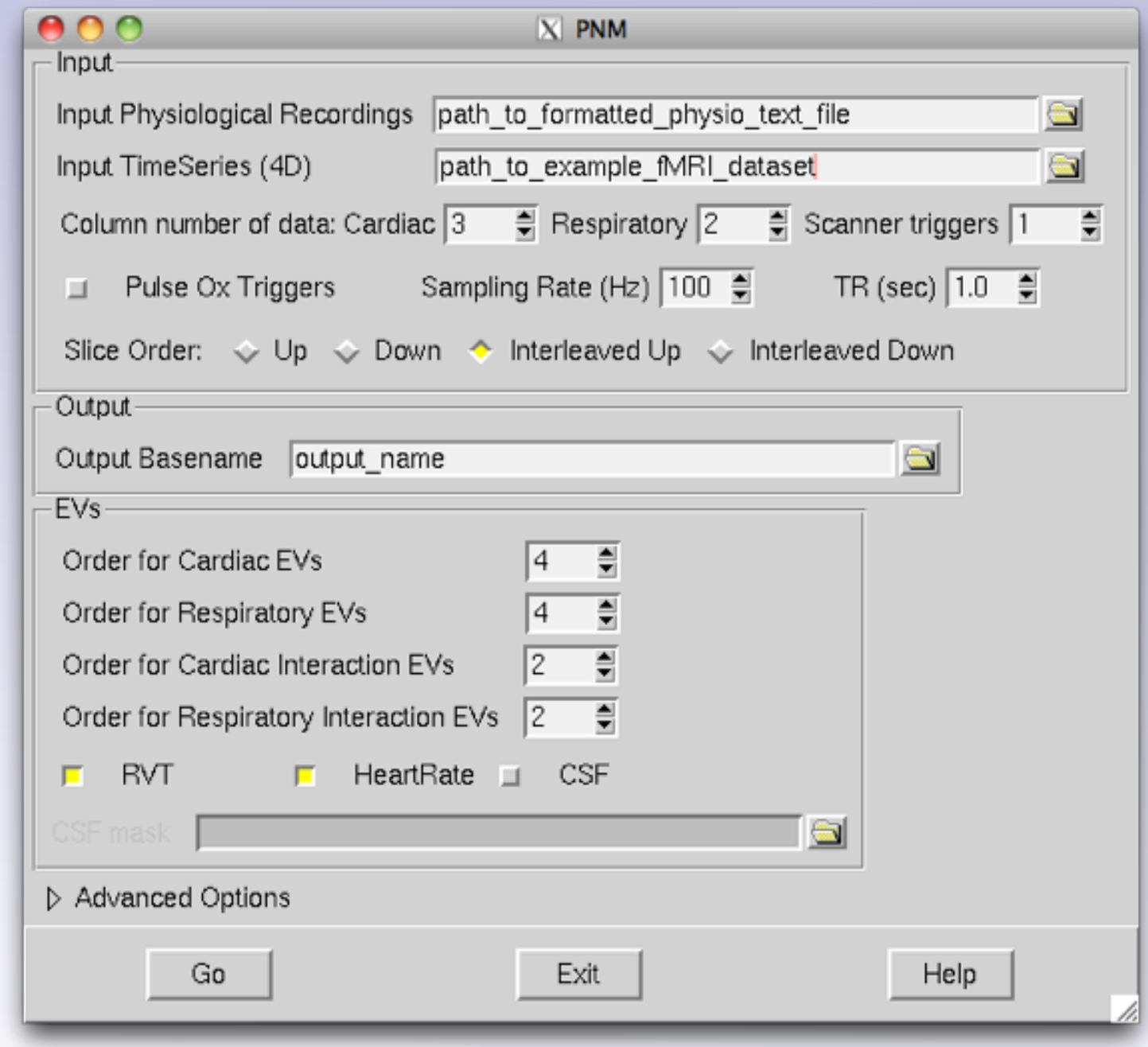

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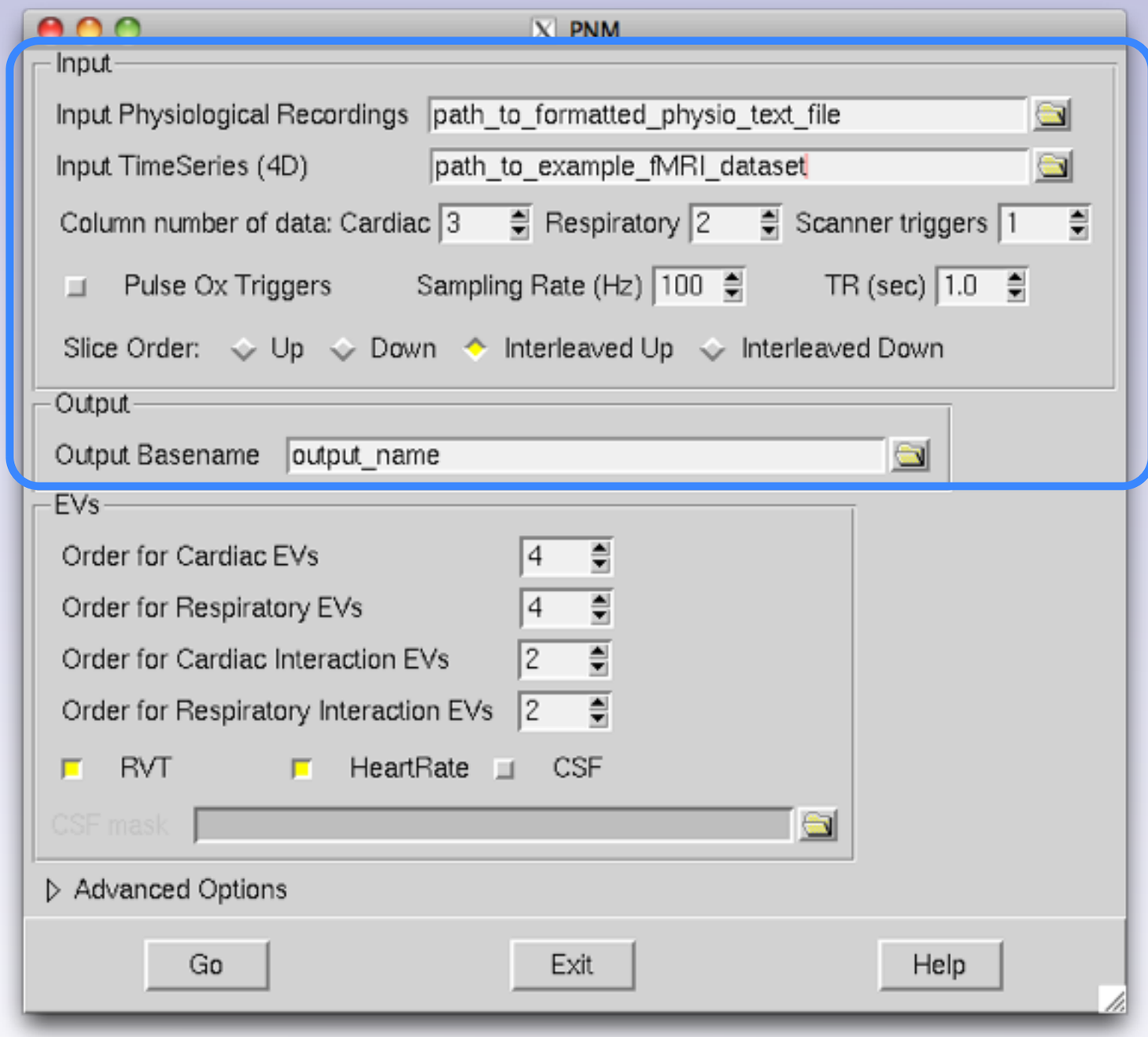

basic configuration options

- paths to inputs
- order of cols in physio file
- physio parameters
- scan parameters

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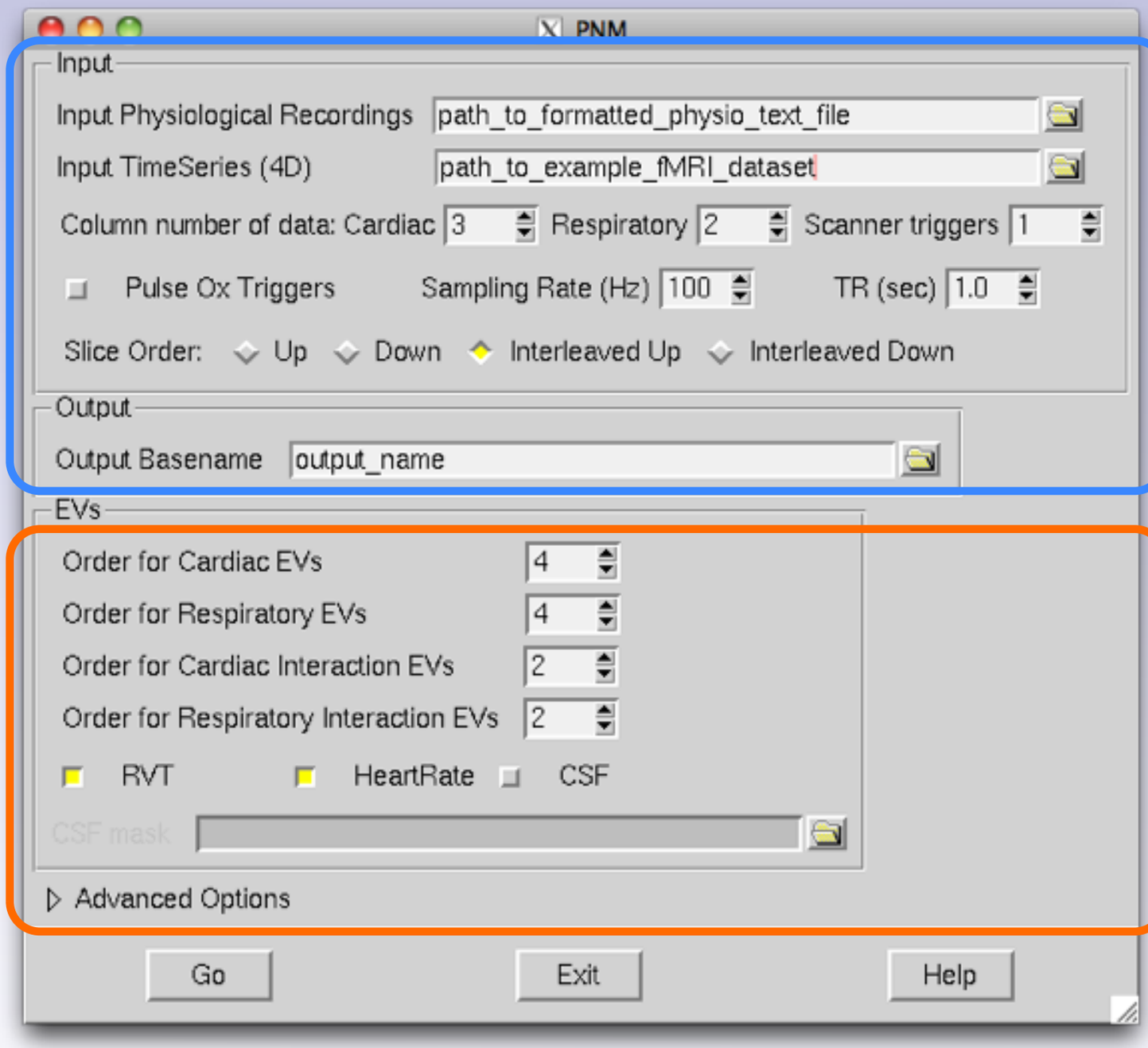

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physio model specifications

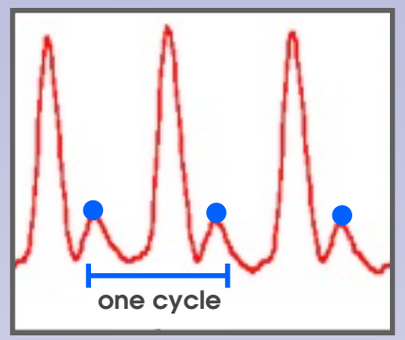
- complexity of model
- additional physio measures
  - RVT
  - HR
  - CSF mask

physio noise modeling

setting the order for physio components

cardiac & respiration:

cardiac and respiration are both quasi-periodic signals:



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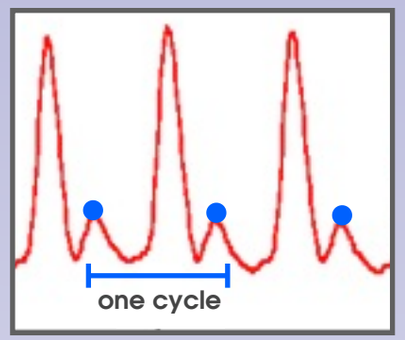

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Fourier Series:

any periodic signal can be fully represented as a sum of sine and cosine terms:

$$f(t) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n \cos(n\,t) + b_n \sin(n\,t)$$

Fourier series of periodic function f(t)
source: mathworld.wolfram.com

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$$\gamma(t) = \sum_{n=1}^{N} a_n \cos(n \cdot \Phi(t)) + b_n \sin(n \cdot \Phi(t))$$

Glover et al. (2000)

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cardiac & respiration:

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$$\gamma(t) = \sum_{n=1}^{N} a_n \cos(n \cdot \Phi(t)) + b_n \sin(n \cdot \Phi(t))$$

Glover et al. (2000)

- N: order of the model
- a_n, b_n: amplitude coefficients
- $\cos(n \cdot \Phi(t))$: cosine regressor
- $\sin(n \cdot \Phi(t))$: sine regressor
- $\gamma(t)$: physio noise component (e.g. cardiac)

physio noise modeling

setting the order for physio components

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Glover et al. (2000)

cosine regressor

sine regressor

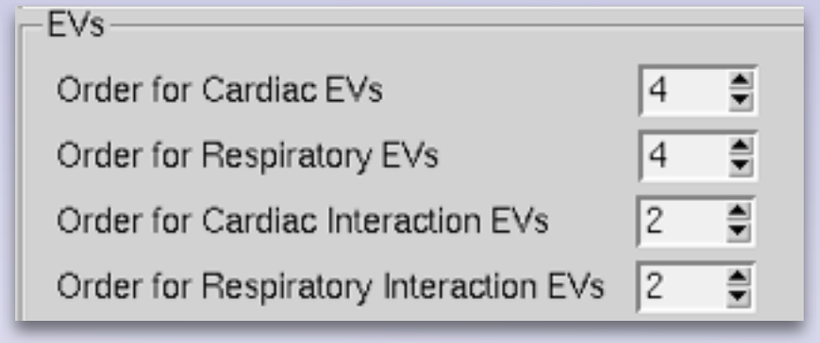
physio noise component (e.g. cardiac)

Note: each order of the model will produce 2 regressors:
- one for the cosine term
- one for the sine term

physio noise modeling

setting the order for physio components

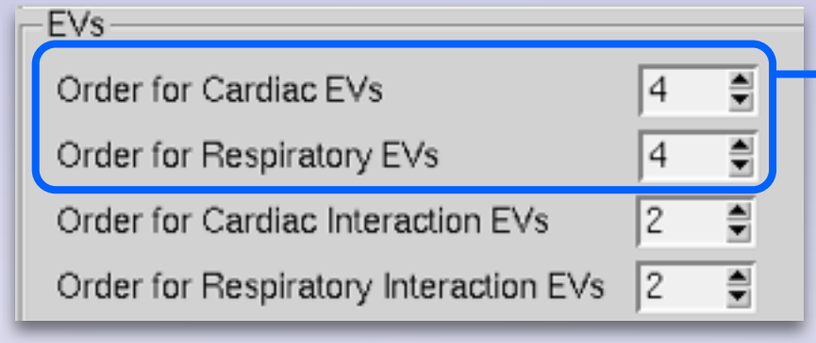
cardiac & respiration:



physio noise modeling

setting the order for physio components

cardiac & respiration:

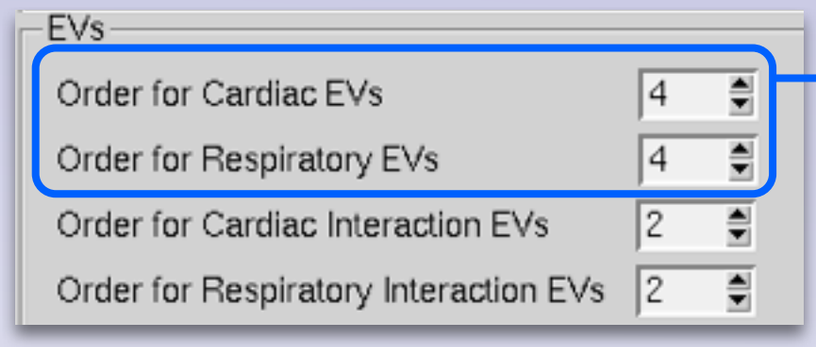


- Use the GUI to set the desired number of regressors for each component

physio noise modeling

setting the order for physio components

cardiac & respiration:



- Use the GUI to set the desired number of regressors for each component

for each physio component (i.e. cardiac, resp):

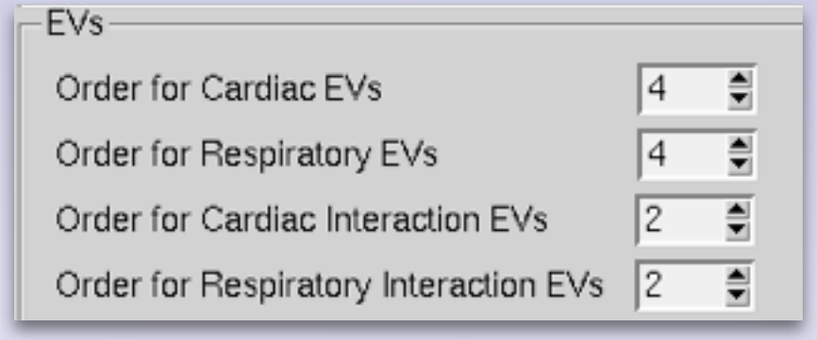
order	frequency	# sine terms	# cosine terms	Total # regressors
1	base	1	1	2
2	1st harmonic	2	2	4
3	2nd harmonic	3	3	6
4	3rd harmonic	4	4	8

physio noise modeling

setting the order for physio components

interaction terms

In addition to modeling cardiac and respiration separately, you can also model interaction effects



physio noise modeling

setting the order for physio components

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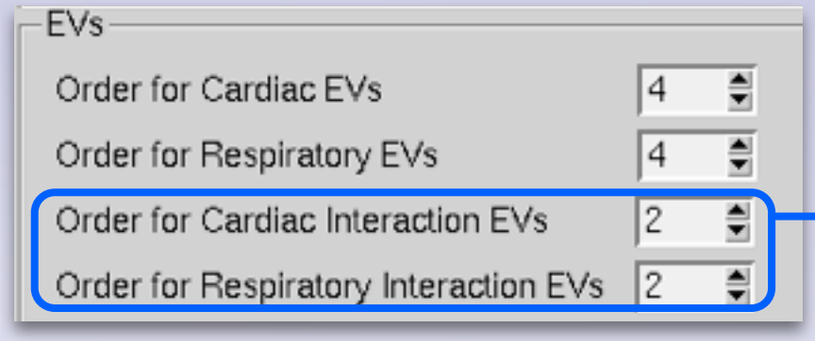


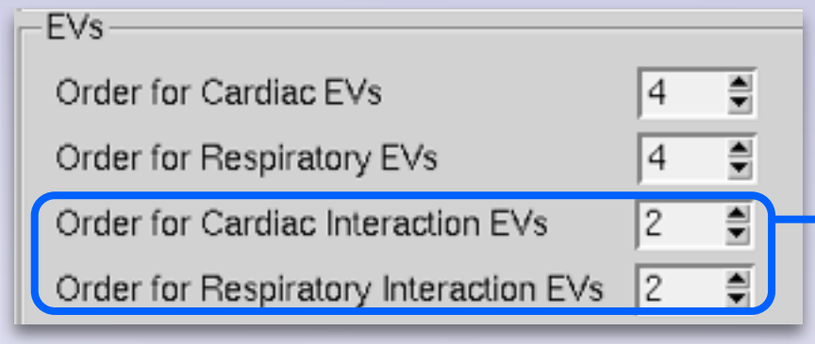
Use the GUI to set the desired number of interaction components

physio noise modeling

setting the order for physio components

interaction terms

In addition to modeling cardiac and respiration separately, you can also model interaction effects



Use the GUI to set the desired number of interaction components

for each unique combination of cardiac and respiratory frequencies, there will be 4 interaction terms produced:

$$\left.\begin{array}{l}\beta\cos(n\cdot\Phi_{card} + m\cdot\Phi_{resp})\\ \beta\sin(n\cdot\Phi_{card} + m\cdot\Phi_{resp})\end{array}\right\}\ \text{additive}$$

$$\left.\begin{array}{l}\beta\cos(n\cdot\Phi_{card} - m\cdot\Phi_{resp})\\ \beta\sin(n\cdot\Phi_{card} - m\cdot\Phi_{resp})\end{array}\right\}\ \text{subtractive}$$

where, n = each order of cardiac interaction term
m = each order of respiration interaction term

physio noise modeling

creating the regressors

physio noise modeling

creating the regressors

After running GUI (or stage1 script)

Within the output directory you'll find a *_pnm1.html file containing physio plots with detected peaks overlaid

physio noise modeling

creating the regressors

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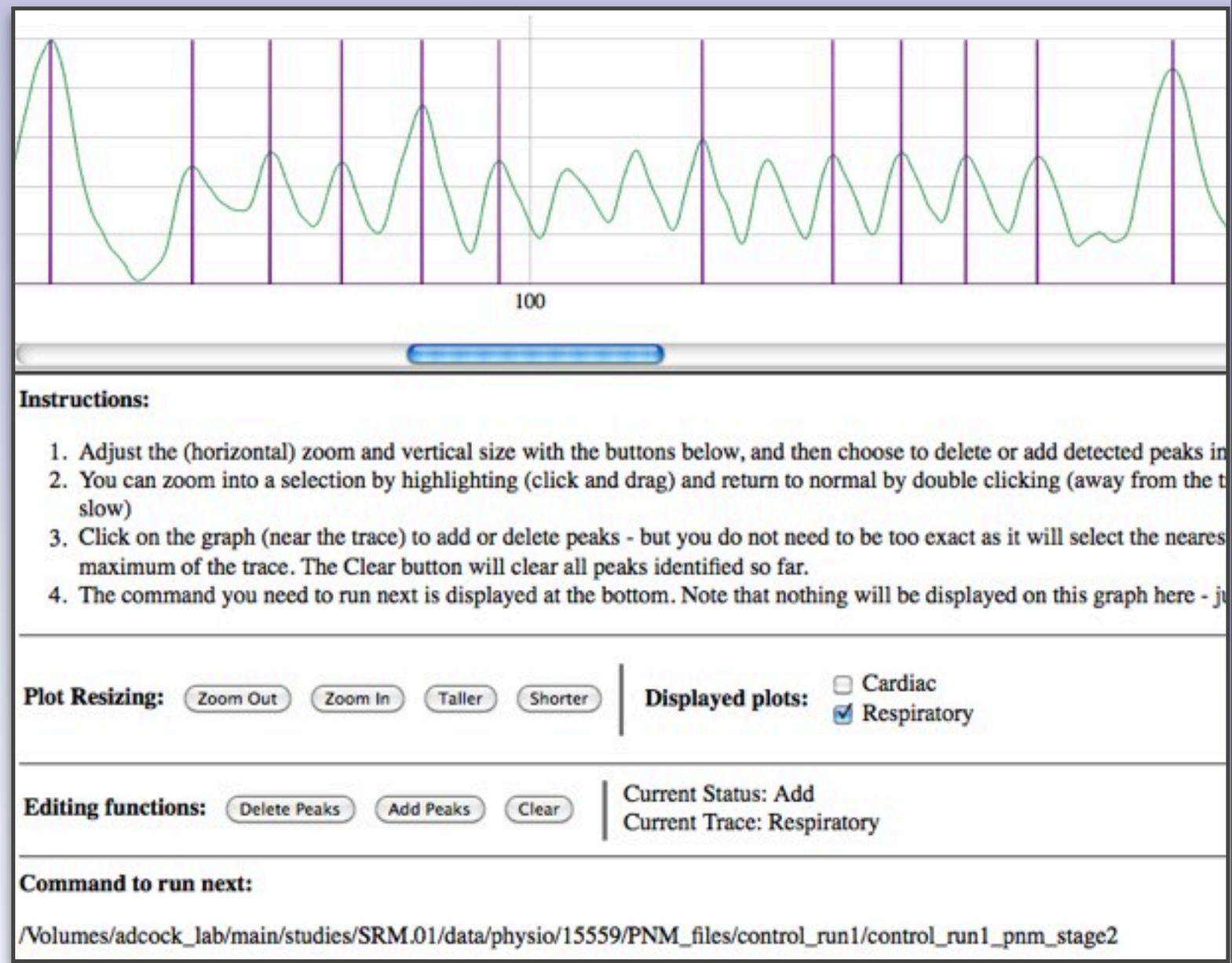

physio noise modeling

creating the regressors

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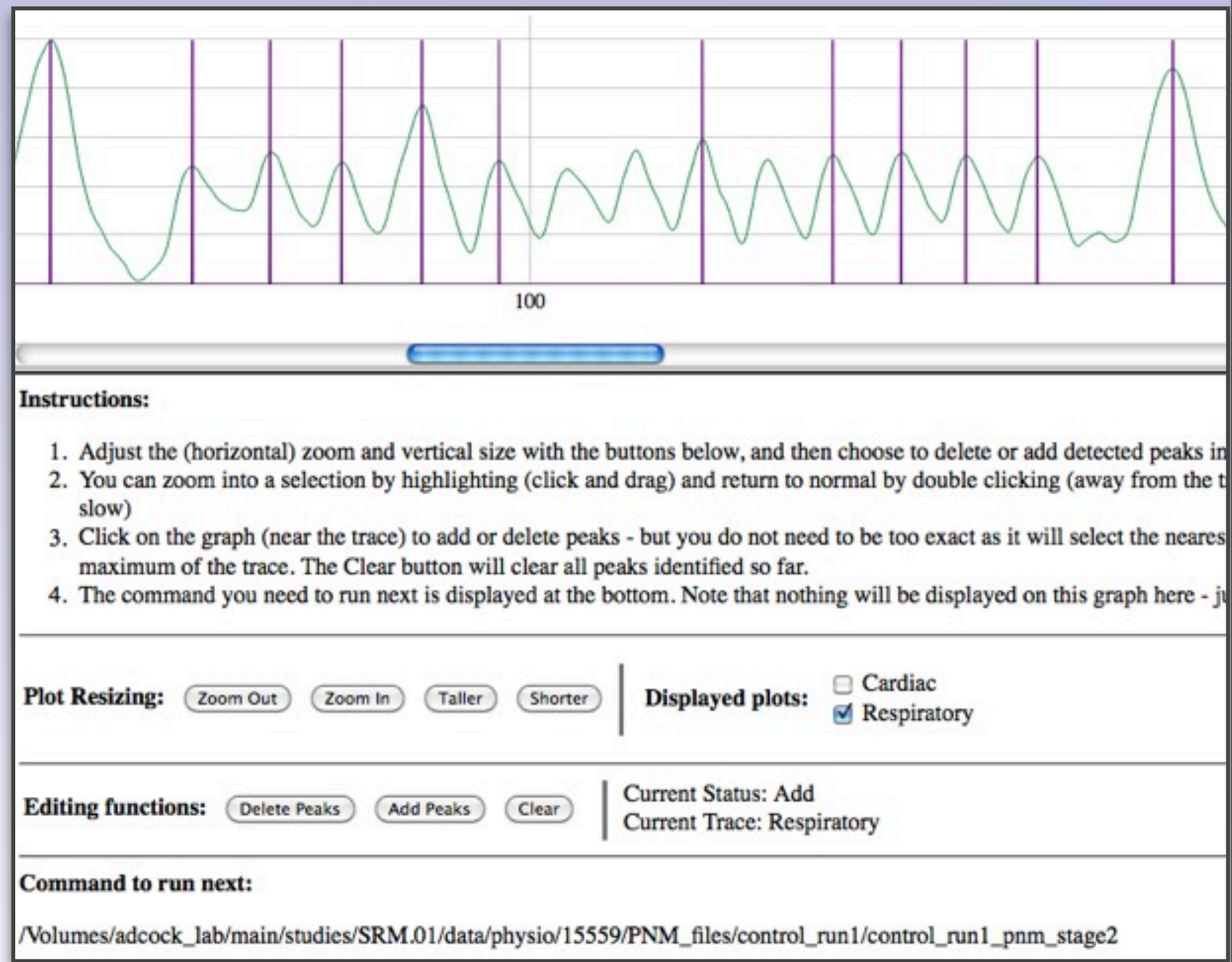
manually confirm peaks

use the interactive window to add missing peaks or remove falsely identified peaks



physio noise modeling

creating the regressors

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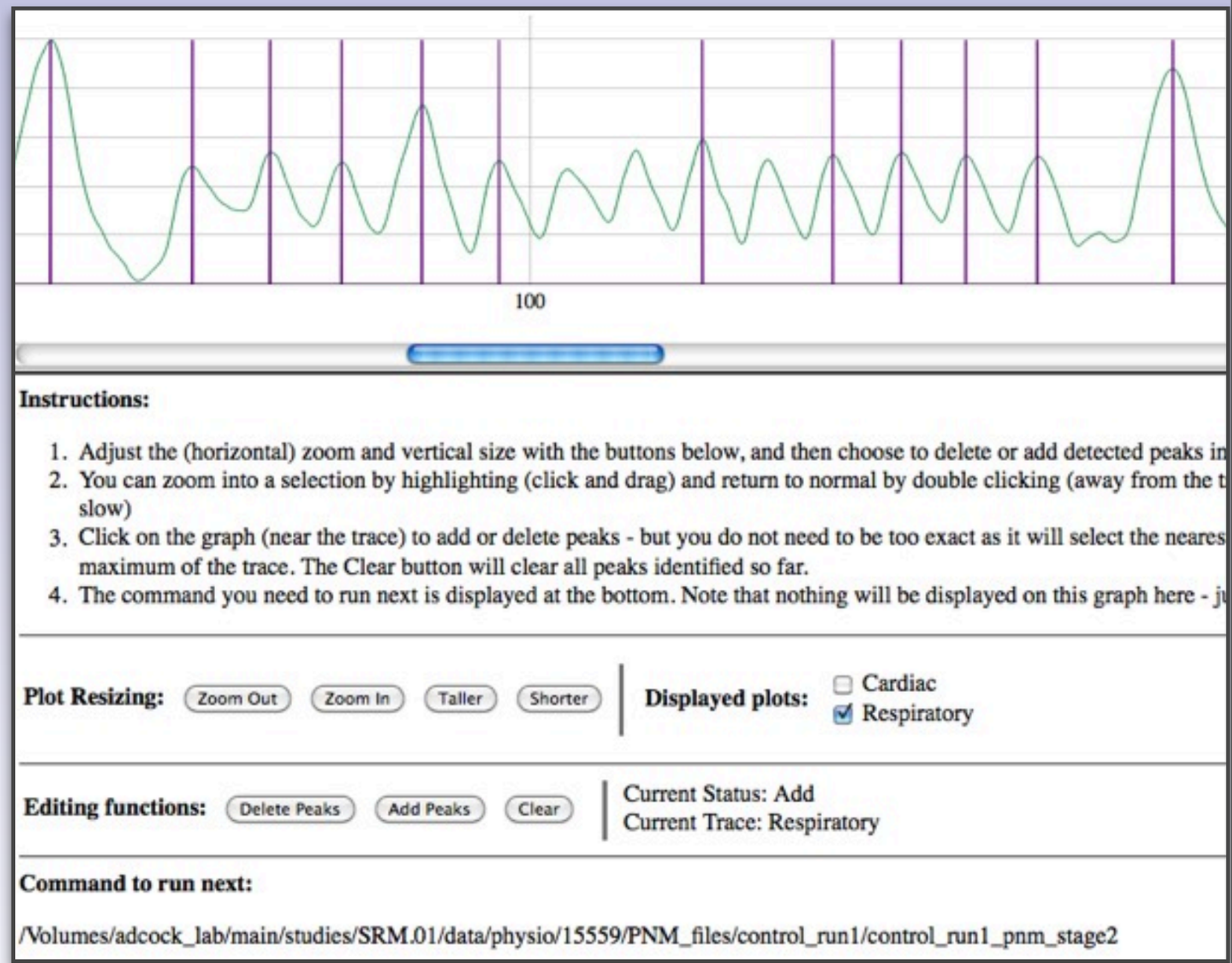
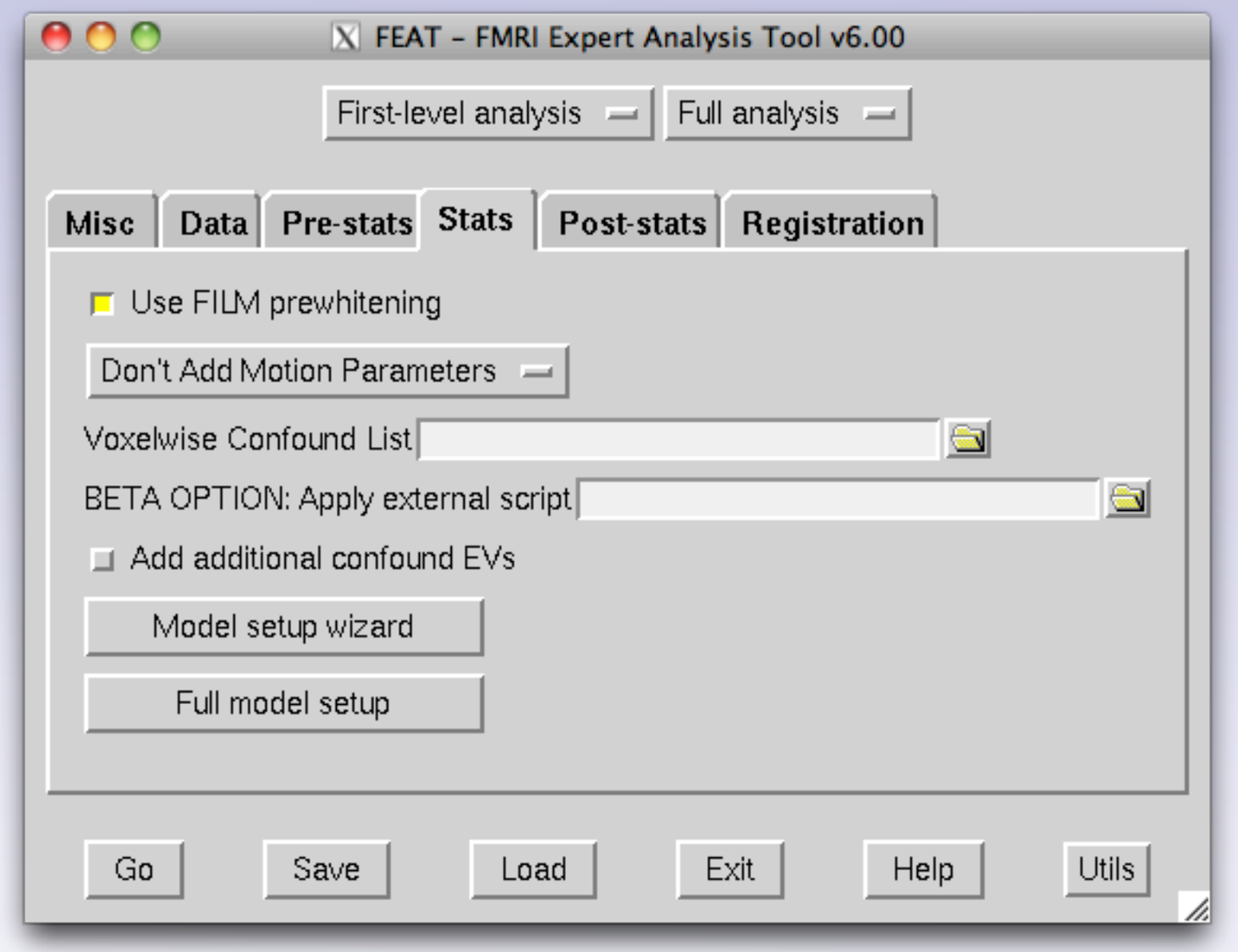
once complete, run the full script listed at the bottom of the window. This will create the regressors as well as additional required files



physio noise modeling

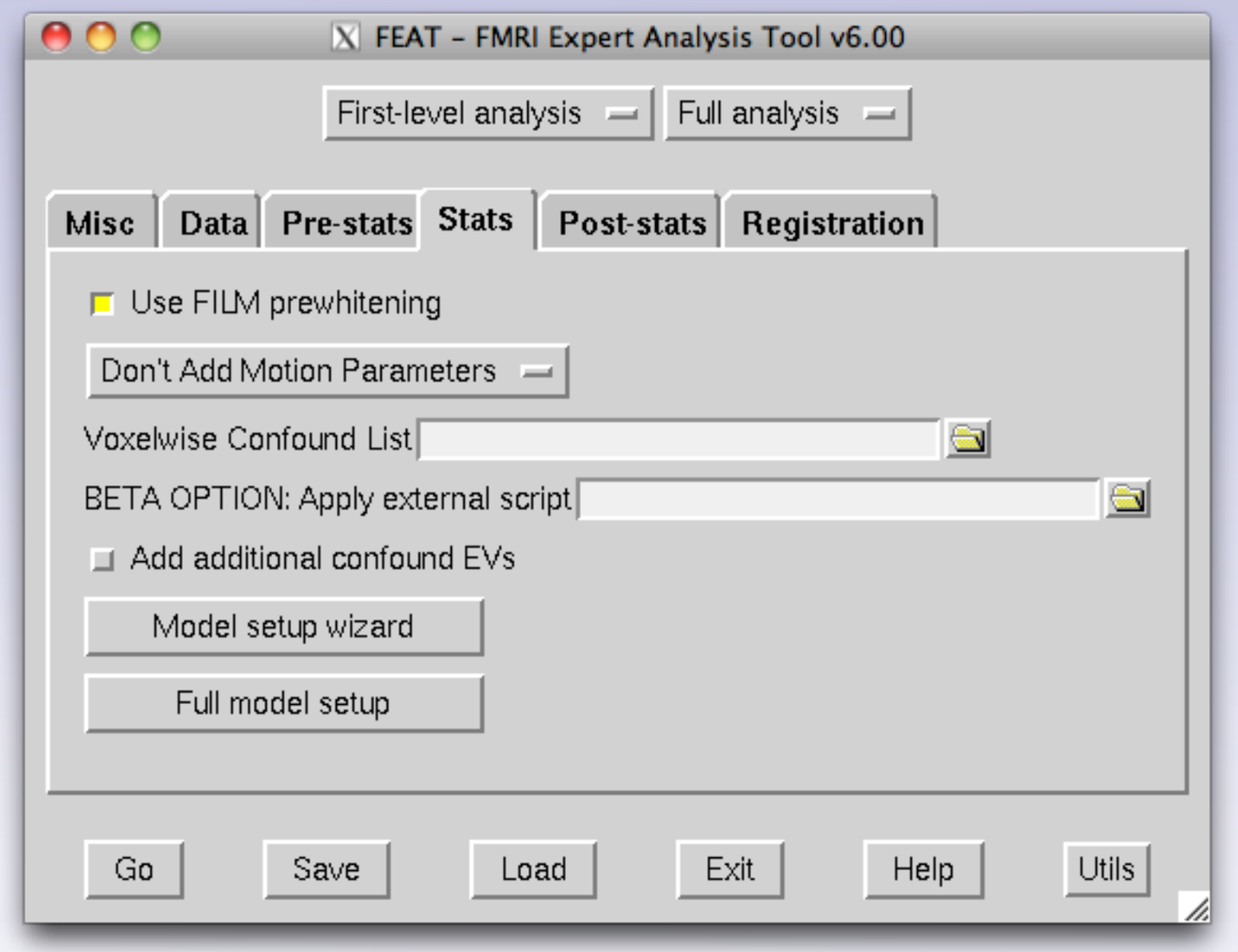
creating the regressors

adding regressors to FEAT model



physio noise modeling

creating the regressors

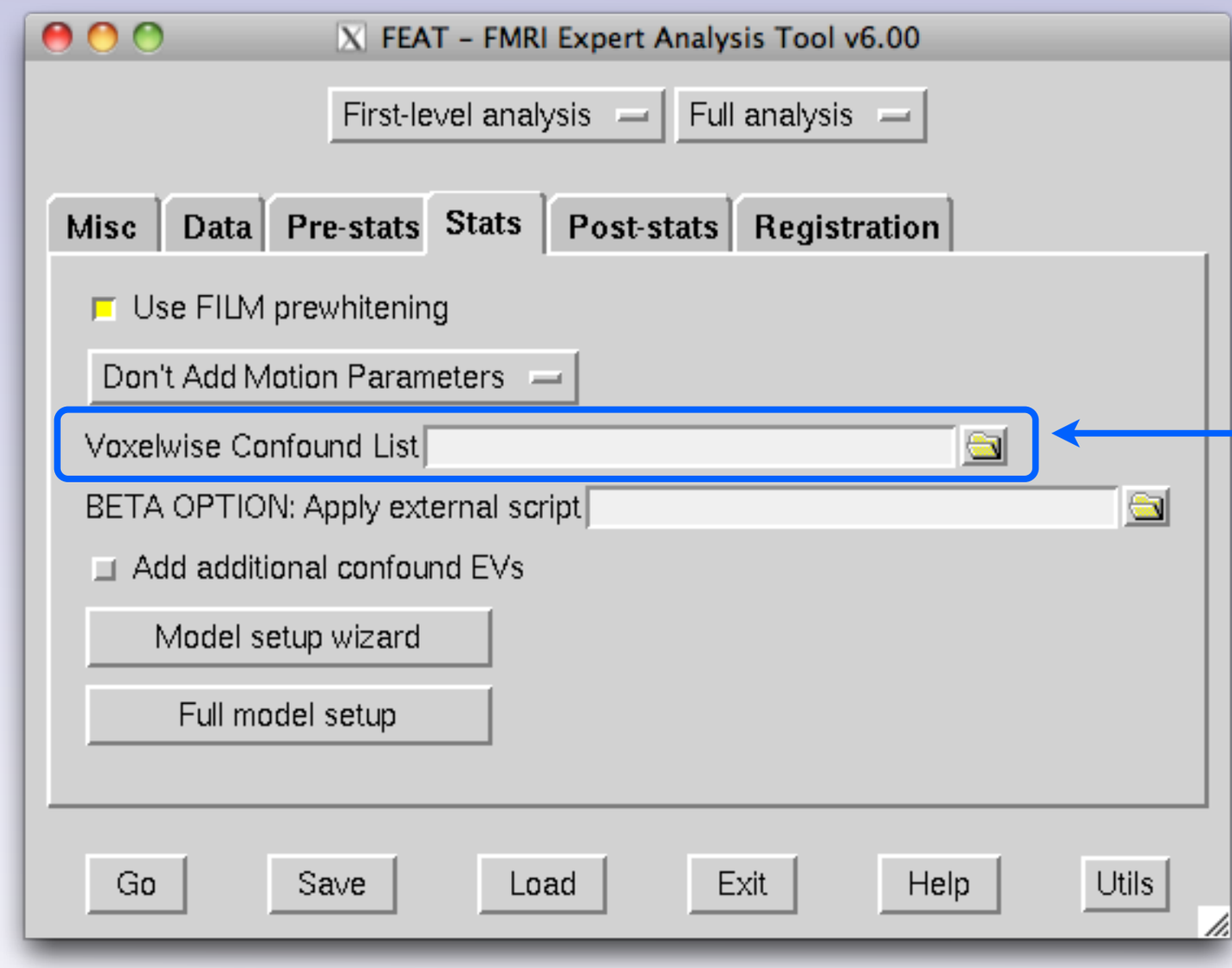


adding regressors to FEAT model

in addition to creating a 4D .nii.gz file for each regressor, the stage2 script will also create a text file containing the paths to each regressor (called *_evlist.txt)

physio noise modeling

creating the regressors



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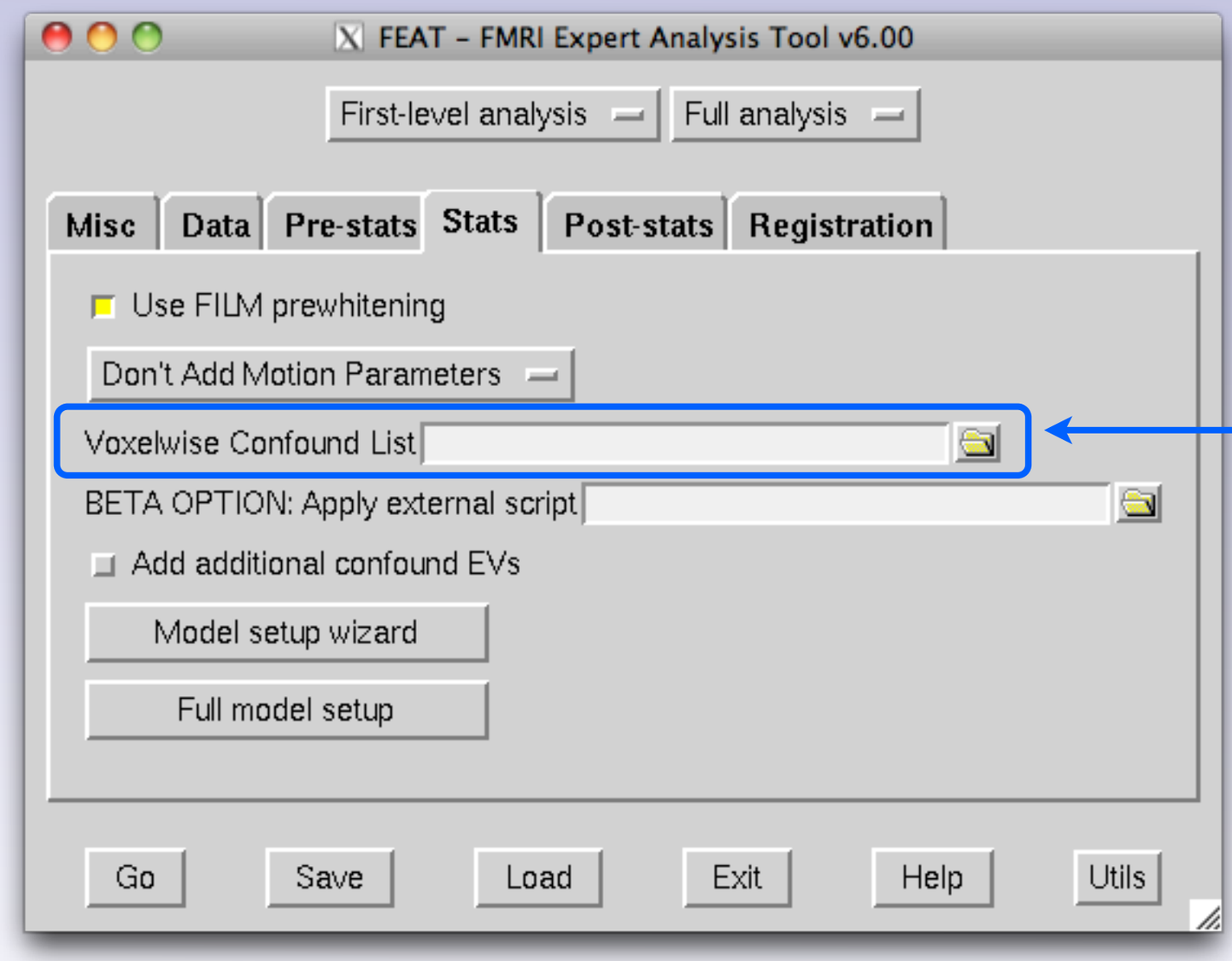
physio noise modeling

creating the regressors



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All physio regressors are automatically treated as confound regressors, meaning any shared variance with EVs of interest will be assigned to the physio regressors

physio noise modeling

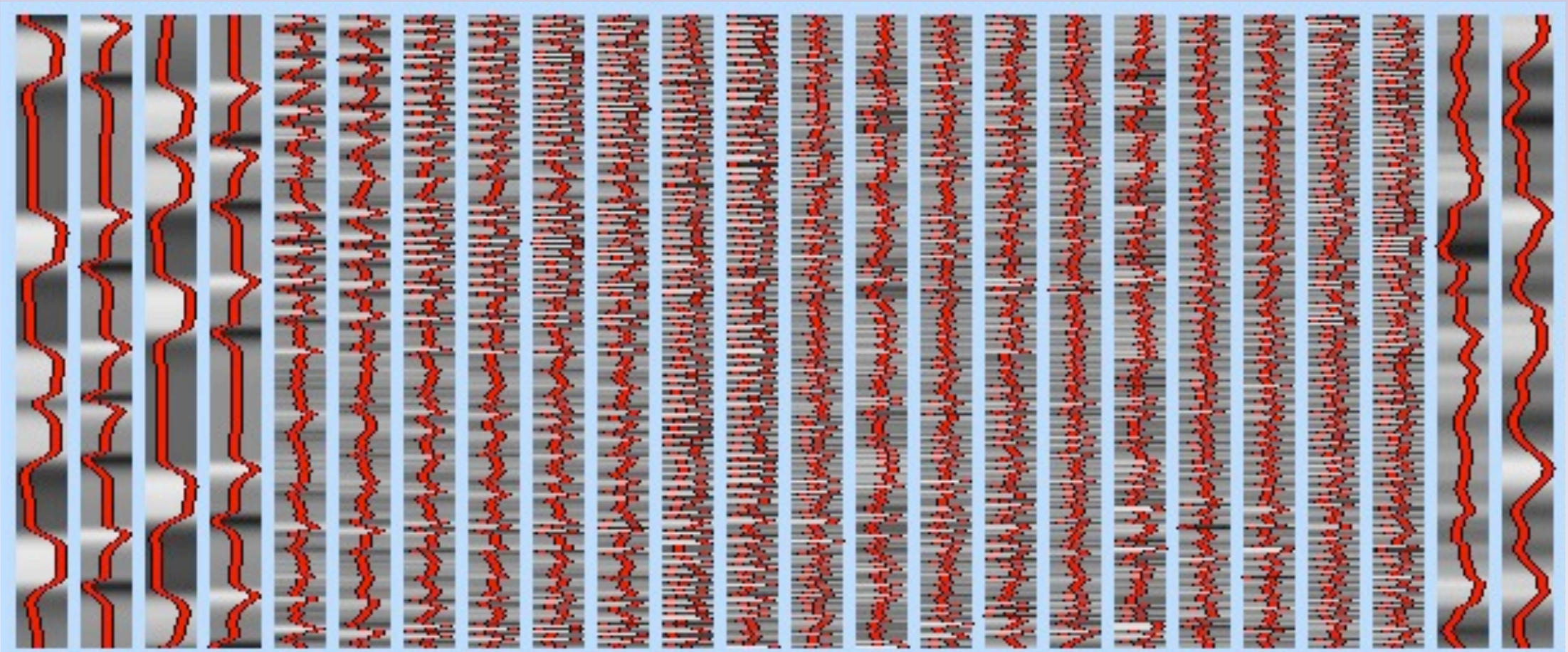
creating the regressors

loaded physio regressors will appear in design matrix

physio noise modeling

creating the regressors

loaded physio regressors will appear in design matrix



RESTREAT	TIAVADEVAR	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc	nfc
-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

physio noise modeling

creating the regressors

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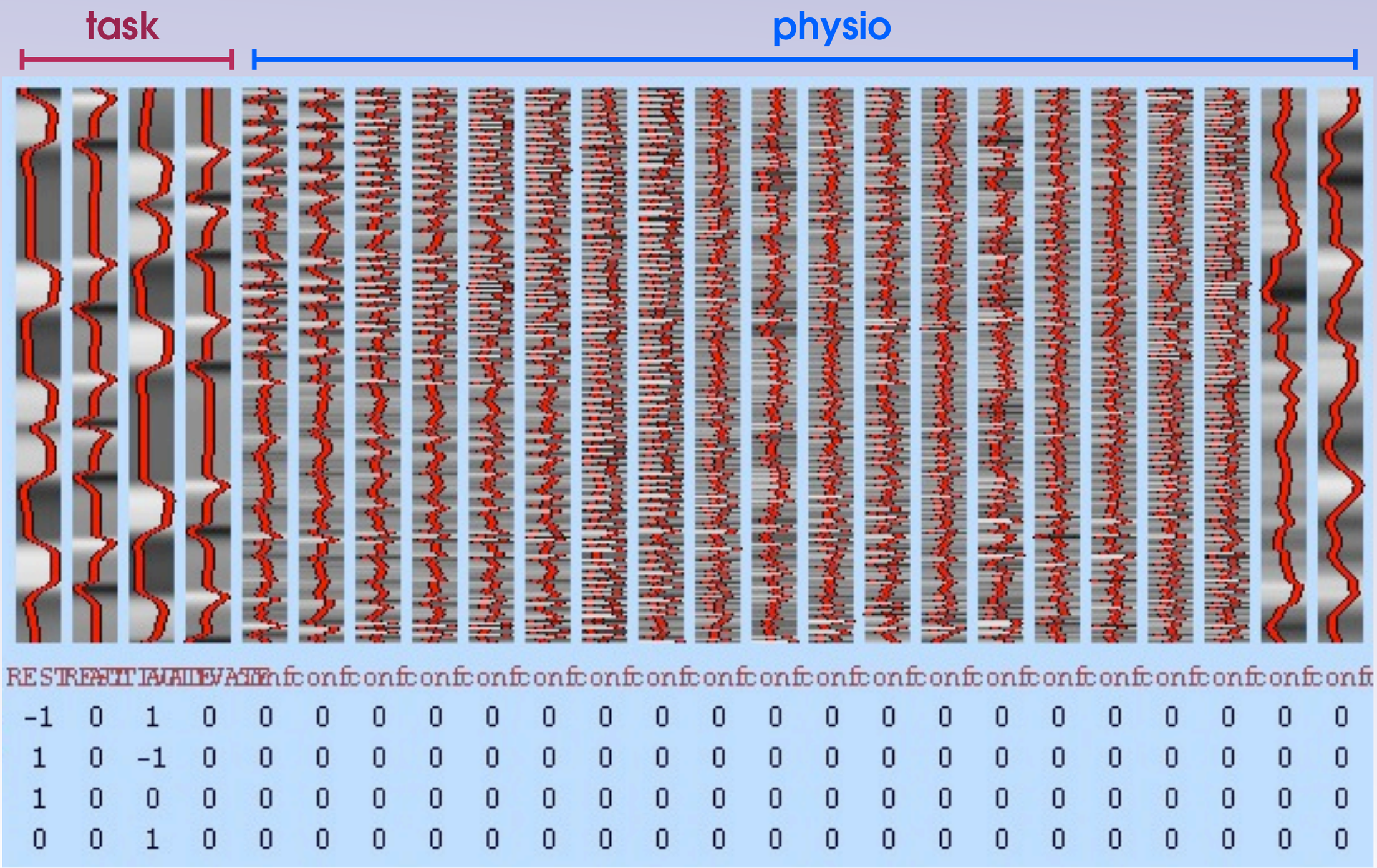

more information

BIAC physio correction methods:

http://wiki.biac.duke.edu/biac:analysis:physiological

Physio Noise Modeling within FSL-5:

http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/PNM

References (not exhaustive)

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2. RVT – Birn et al. (2006). NeuroImage 31: 1536–48
3. HR – Shmueli et al. (2007). NeuroImage 38: 306–20
4. HR – Chang et al. (2009). NeuroImage 44: 857–69
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6. PNM – Harvey et al. (2008). J Magn Reson Imaging 28: 1337–44
7. CO2 – Cohen-Adad et al. (2010). NeuroImage 50: 1074–84