Physiological Confounds in fMRI

13/06/24

Burak Akin

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Confounds? or Noise? and Neuronal Activity? or Brain Activity?

- What is the definition of the Noise?
  - Anything doesn't fit to a model
  - Non-task related variability
  - Just anything looks like this →

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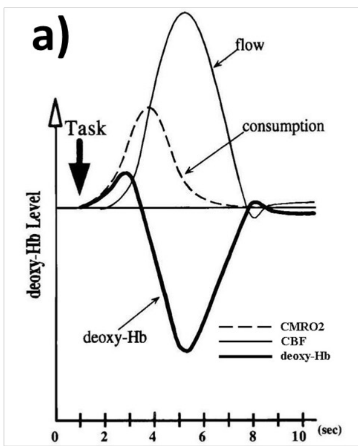
Functional MRI

- T2*-weighted imaging sensitive to paramagnetic deoxyhaemoglobin concentration in the blood
- Blood-oxygenation level dependent (BOLD) effect



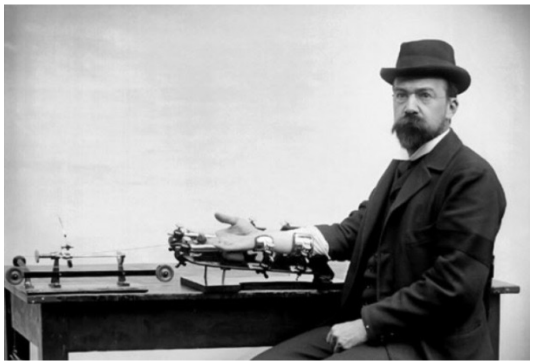
Glover et.al 1999

Respiration

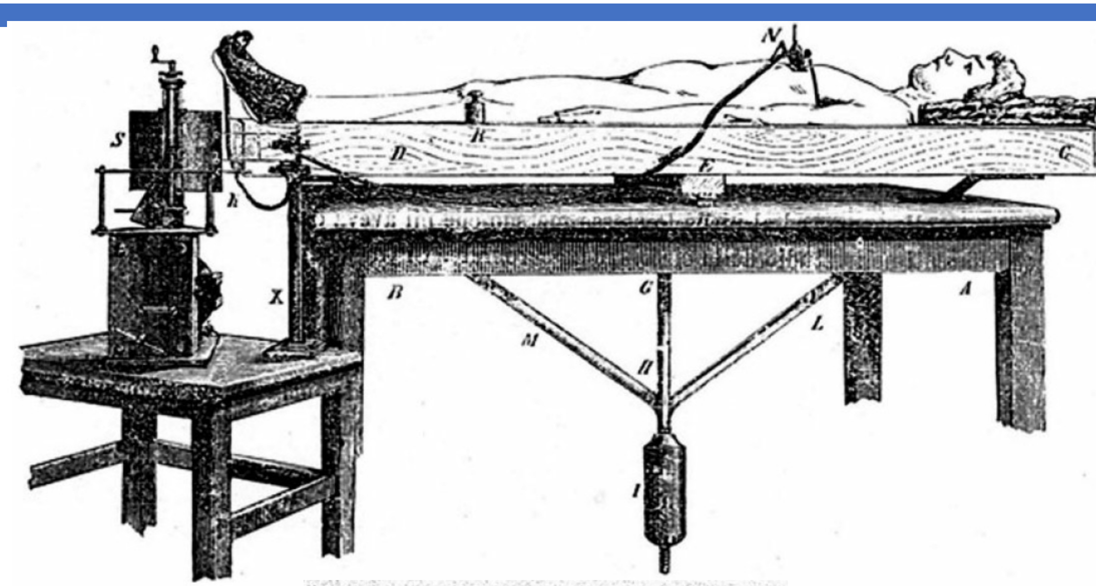
Cardiac pulsations

The man who weighed thoughts

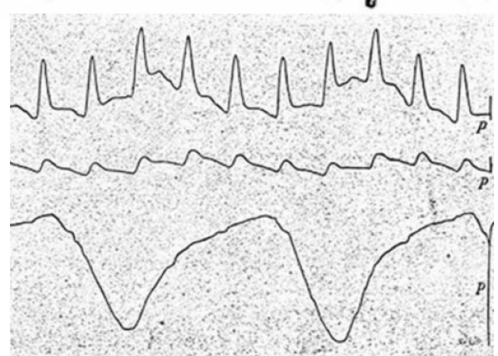
Early cerebral blood flow(CBF) measurements



Angelo Mosso (1846 -1910)



Turin - Italy



Mosso et.al 1880

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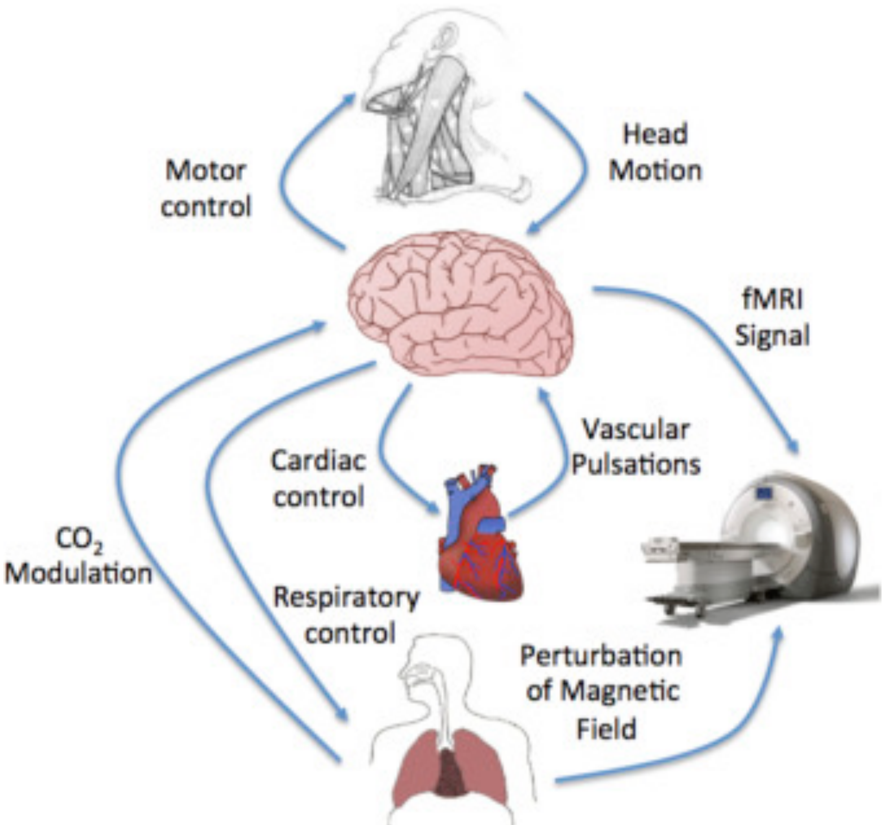
Potential noise sources in fMRI



Liu TT, Neuroimage 2016

- Noise
  - Hardware related
  - Physiological
  - Motion
- Hardware related
  - Scanner drift
  - Thermal noise
- Motion
  - Respiration related
  - Cardiac related
  - Task related
  - Other head motion

- Physiological
  - Respiration
    - Time-locked
    - B0-field
    - CO_2
    - Blood flow
  - Cardiac
    - Time-locked
    - Motion-related
    - Blood flow

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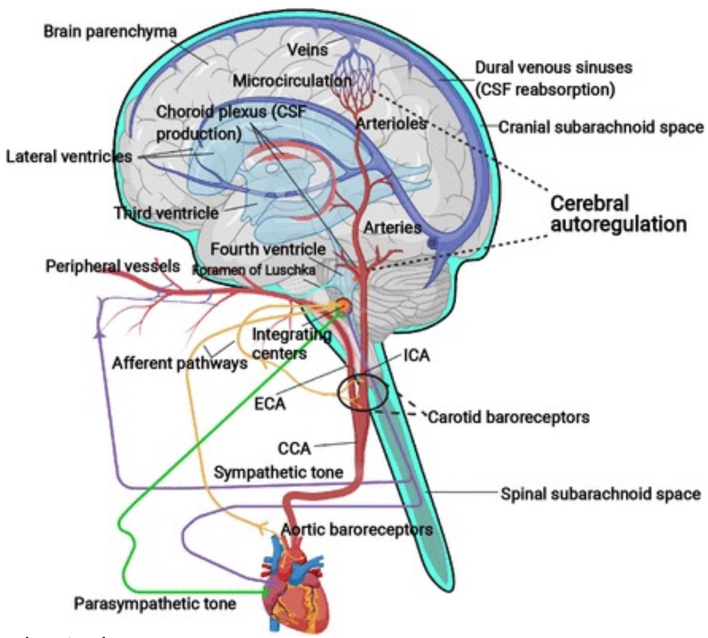
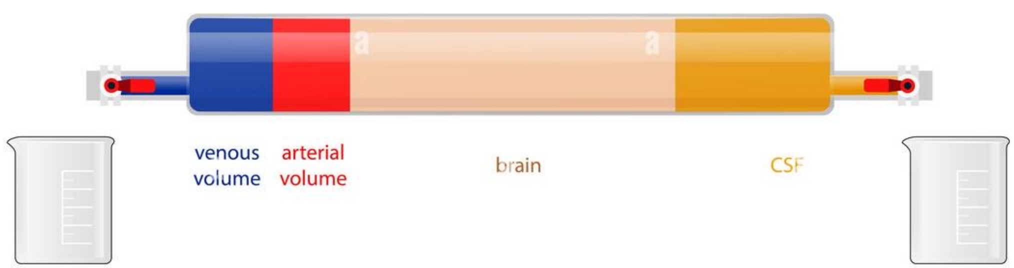
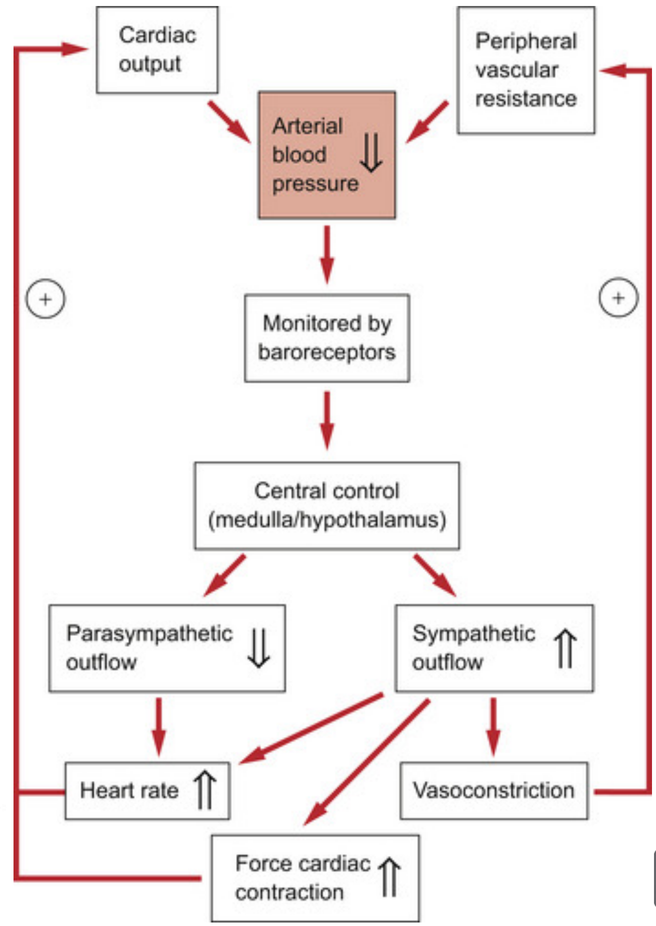
Potential noise sources in fMRI



Garcia et, al.2021





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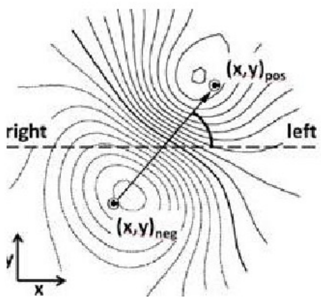
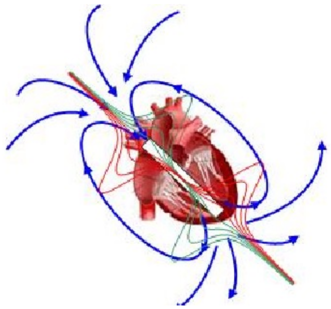
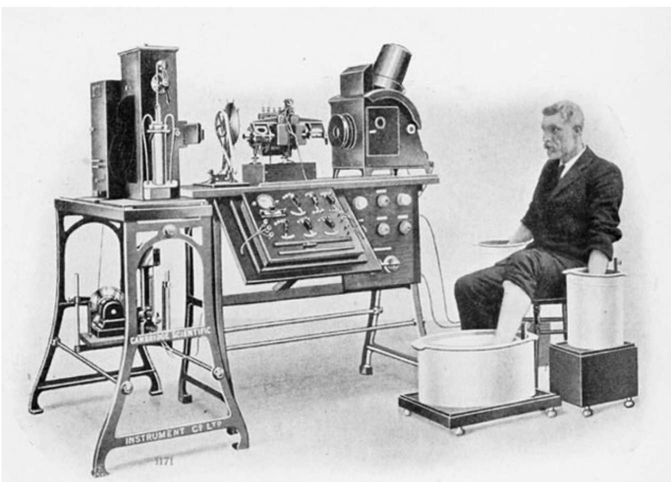
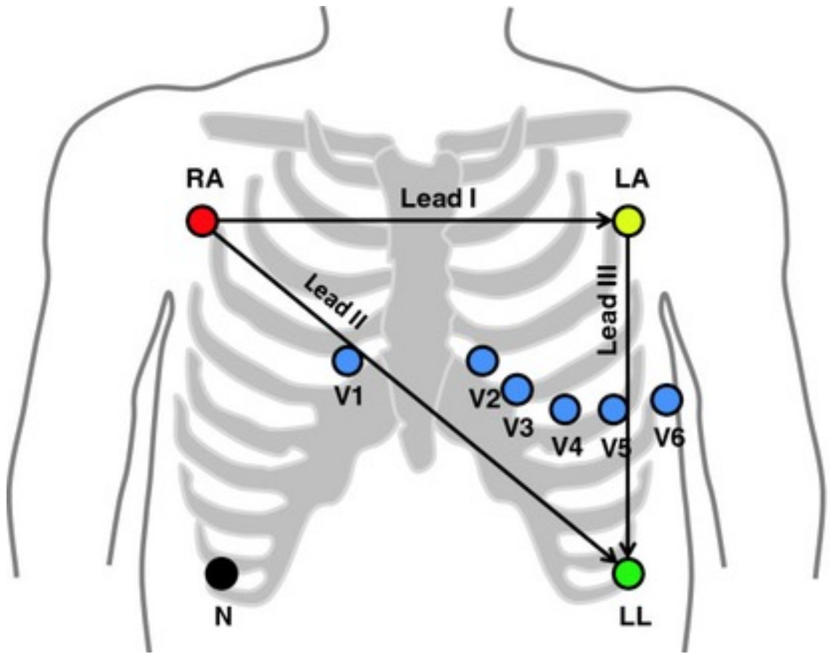
How do we measure physiological signals? Cardiac activity







Photograph of a Complete Electrocardiograph, Showing the Manner in which the Electrodes are Attached to the Patient, In this Case the Hands and One Foot Being Immersed in Jars of Salt Solution



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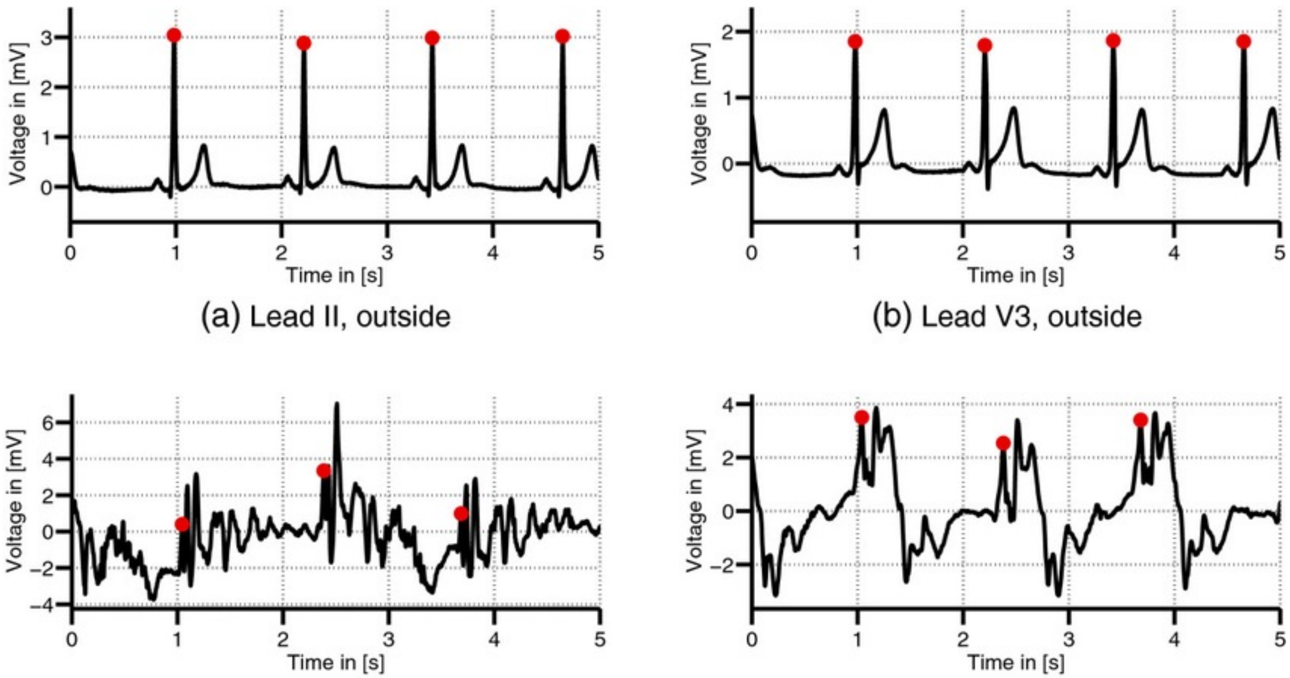
How do we measure physiological signals?

How do we measure physiological signals?

- ECG inside MRI
- The magneto-hydrodynamic effect : the motion of the blood

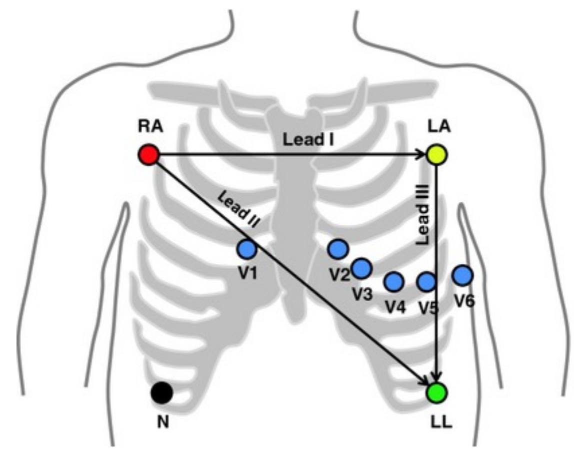


(a) Lead II, outside

(b) Lead V3, outside

(c) Lead II, inside, Ff

(d) Lead V3, inside, Ff



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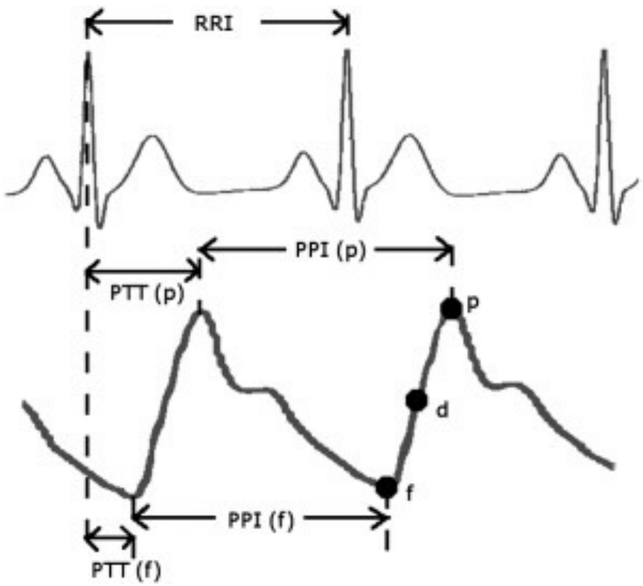
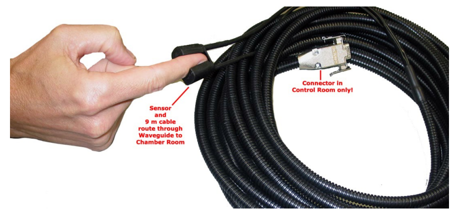
Pulse Oximeter

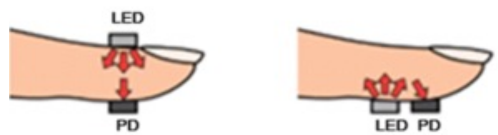


ECG

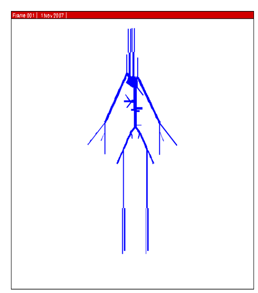
Pulse

Schäfer et, al.2012

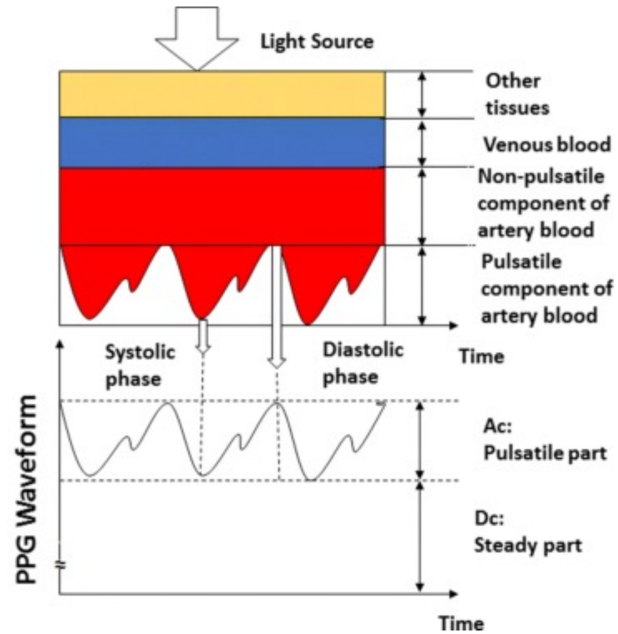




How accurate is pulse rate variability as an estimate of heart rate variability?



http://haemod.uk/nektar



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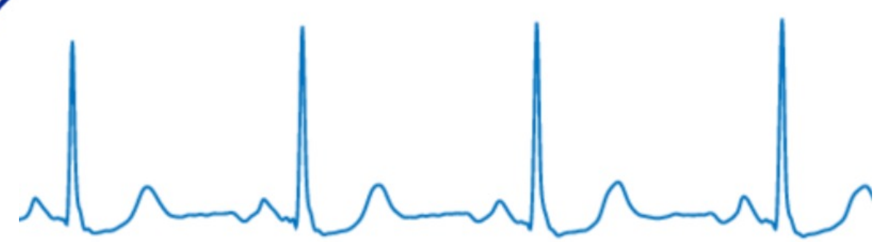
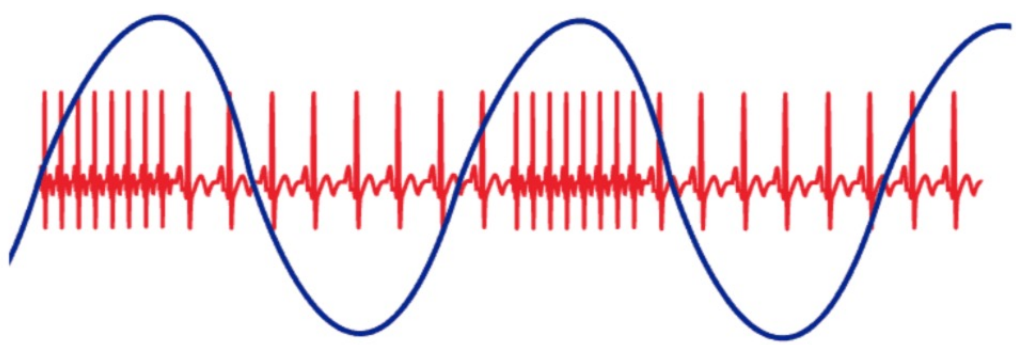
What are the characteristics of physiological signals?

Periodicity



Variability & Interaction



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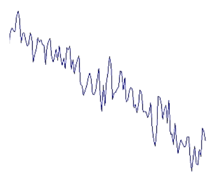
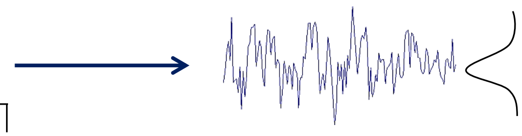
Functional MRI
Preprocessing

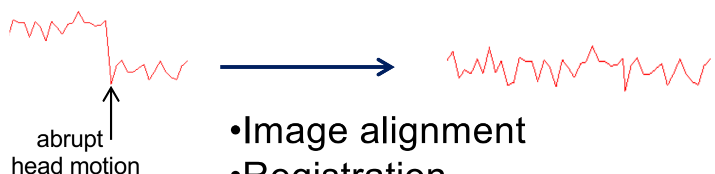
•fMRI images are not ready to do statistics on them.
    •They need to be “conditioned”

•Baseline wander correction
•Trend removal
•Scanner drift removal

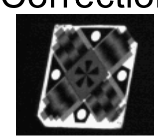


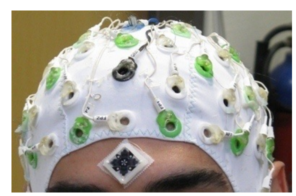


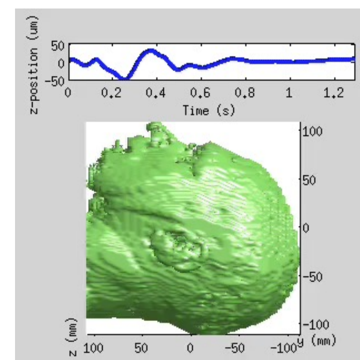
•Physiological noise correction
•Skull stripping
•Spectral filtering
•Smoothing



•Image alignment
•Registration
•Motion Correction







AFNI! MATLAB FSL FMRISTAT BrainVoyager SPM python™

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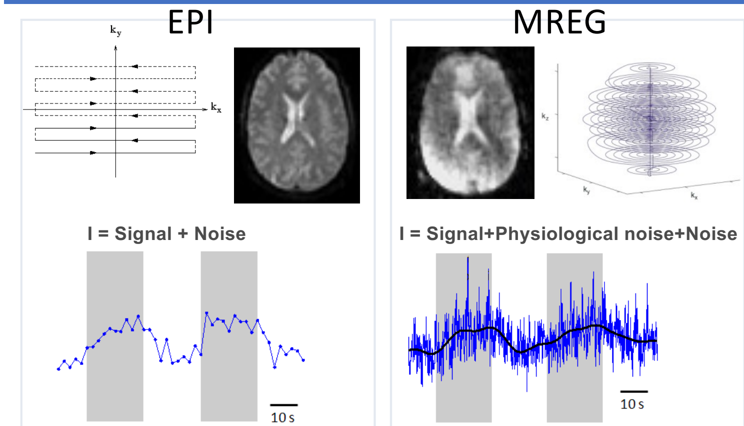
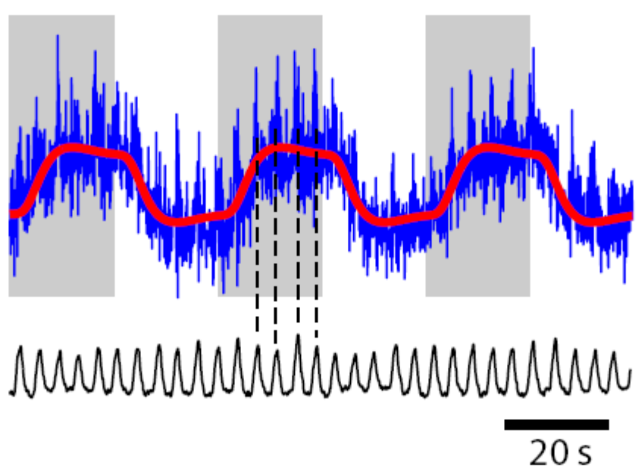
Improving temporal resolution

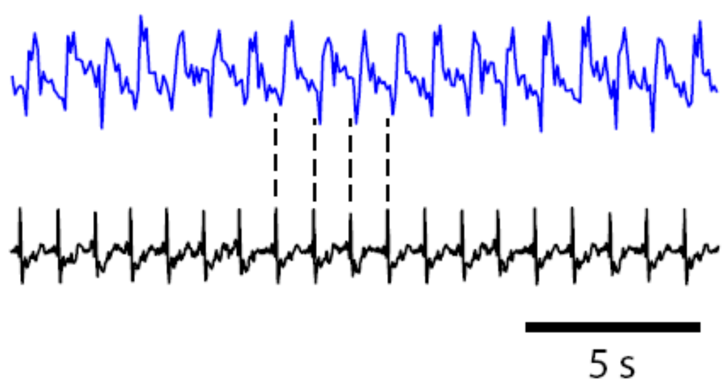
Fast fMRI



- Fast fMRI opens new application areas

→ Improved detectability of the patterns
→ Dynamic connectivity mapping
→ Lag thread analysis
→ Physiological noise removal





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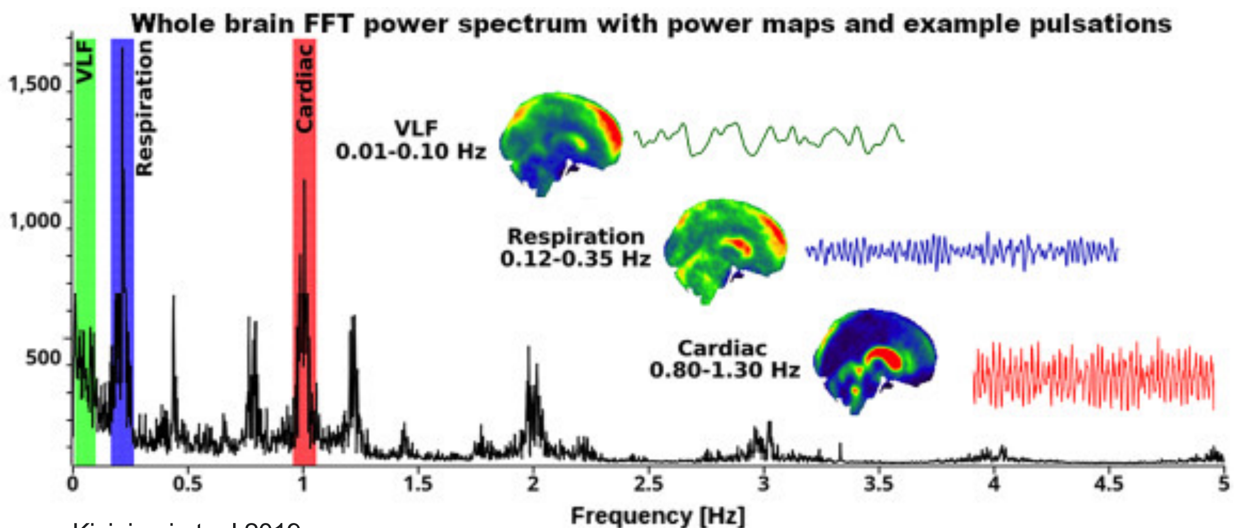
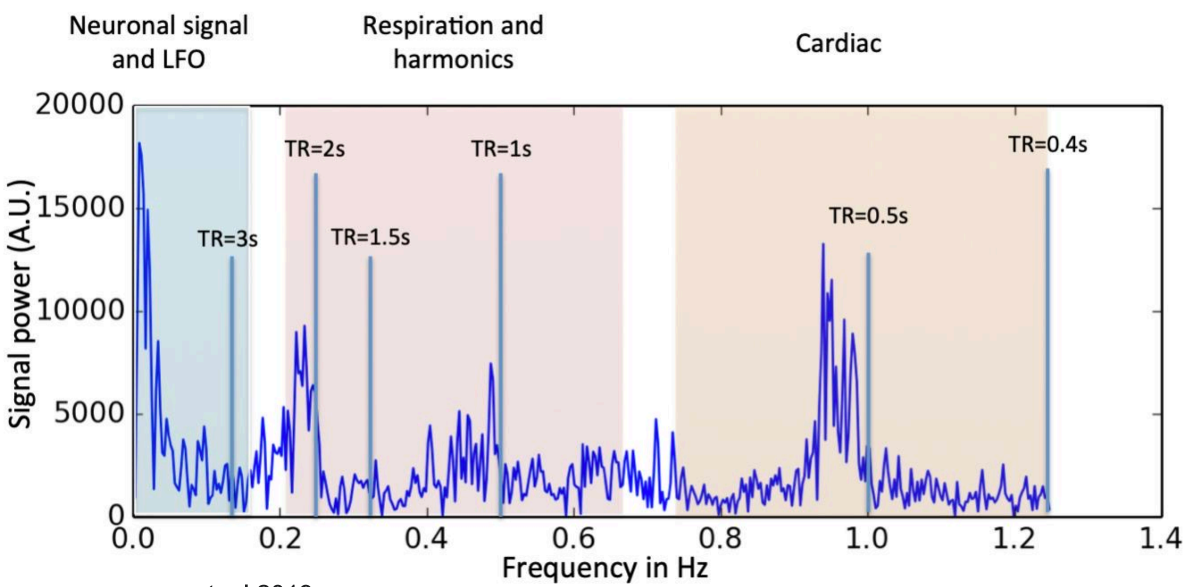
Improving temporal resolution
Fast fMRI



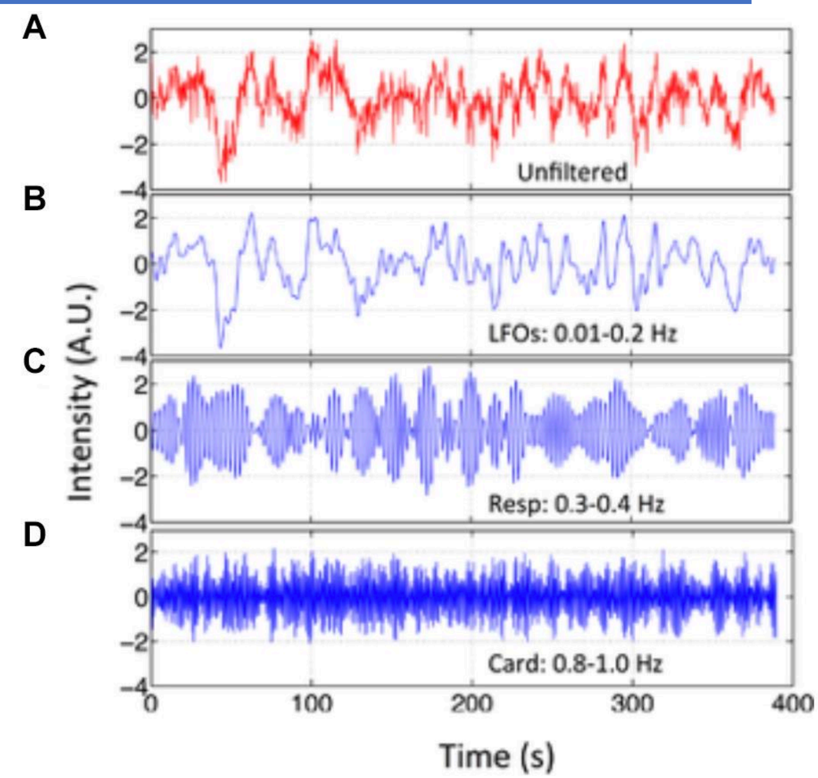
Kiviniemi et, al.2019

Improving temporal resolution

Fast fMRI



Tong et, al.2019



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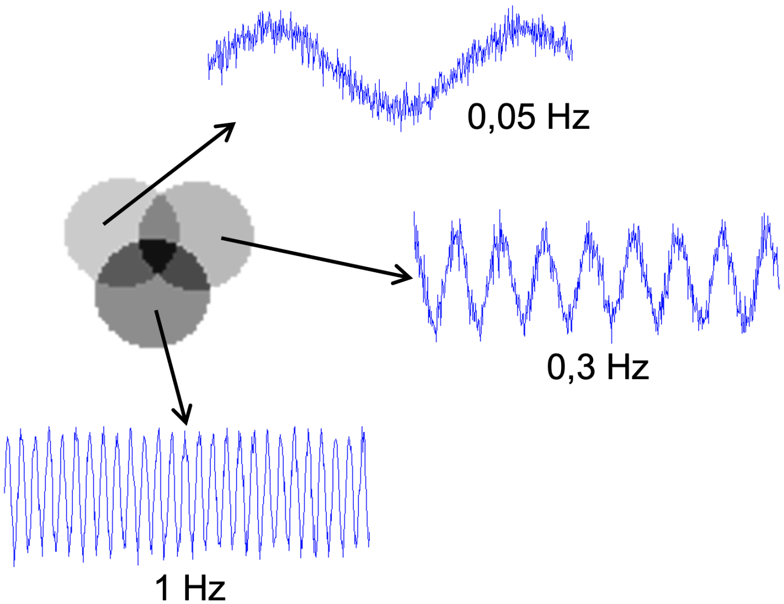
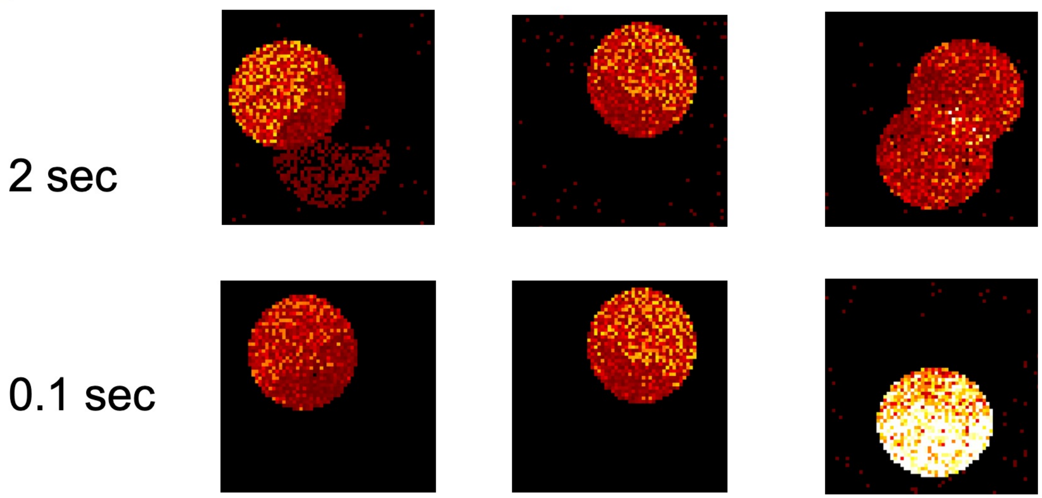
Improving temporal resolution

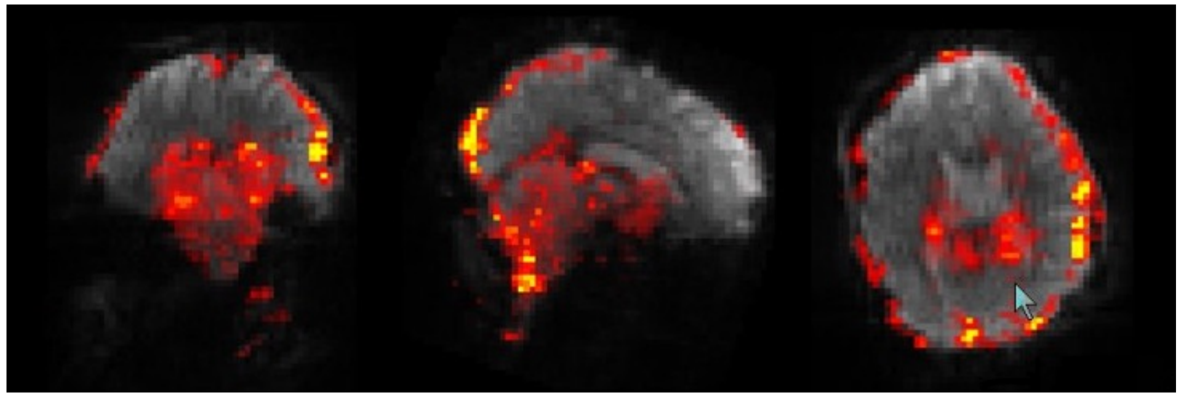
Fast fMRI



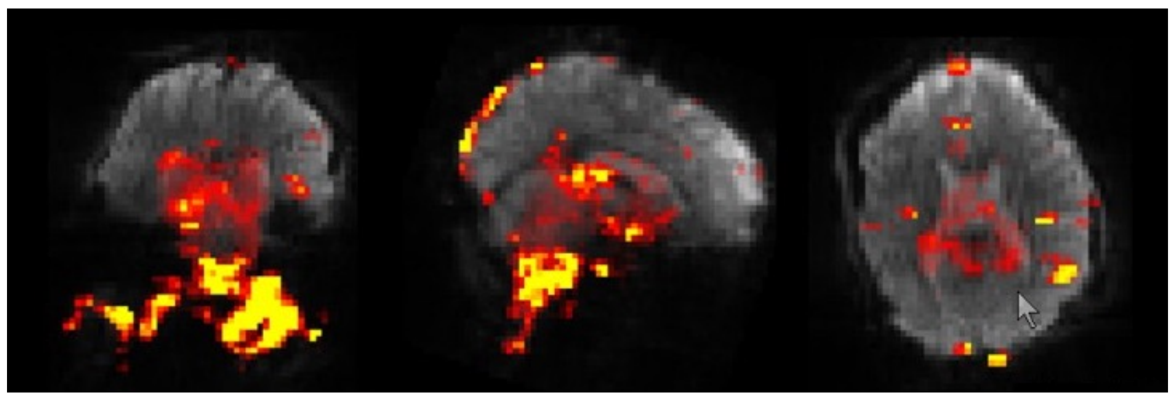


What are the characteristics of physiological signals ?

Respiratory 0.3 Hz



Cardiac 1.3 Hz



How to denoise fMRI data?

- Modeling task paradigm carefully
- Measuring potential confounds externally
- Regressing them from fMRI time series

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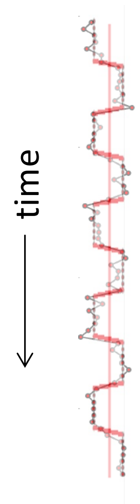
General Linear Model(GLM)

Y	=	X	.	β	+	ε
Observed data		Design matrix		Parameters		Error



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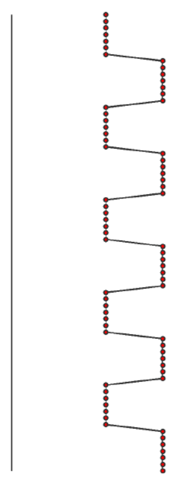
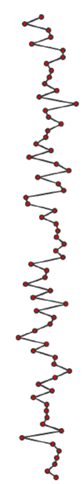


·

$$\begin{bmatrix} \beta_0 \\ \beta_1 \end{bmatrix}$$

+



$\beta = (X^TX)^{-1}X^TY$

(2xn) (nx2) (2xn) (nx1)

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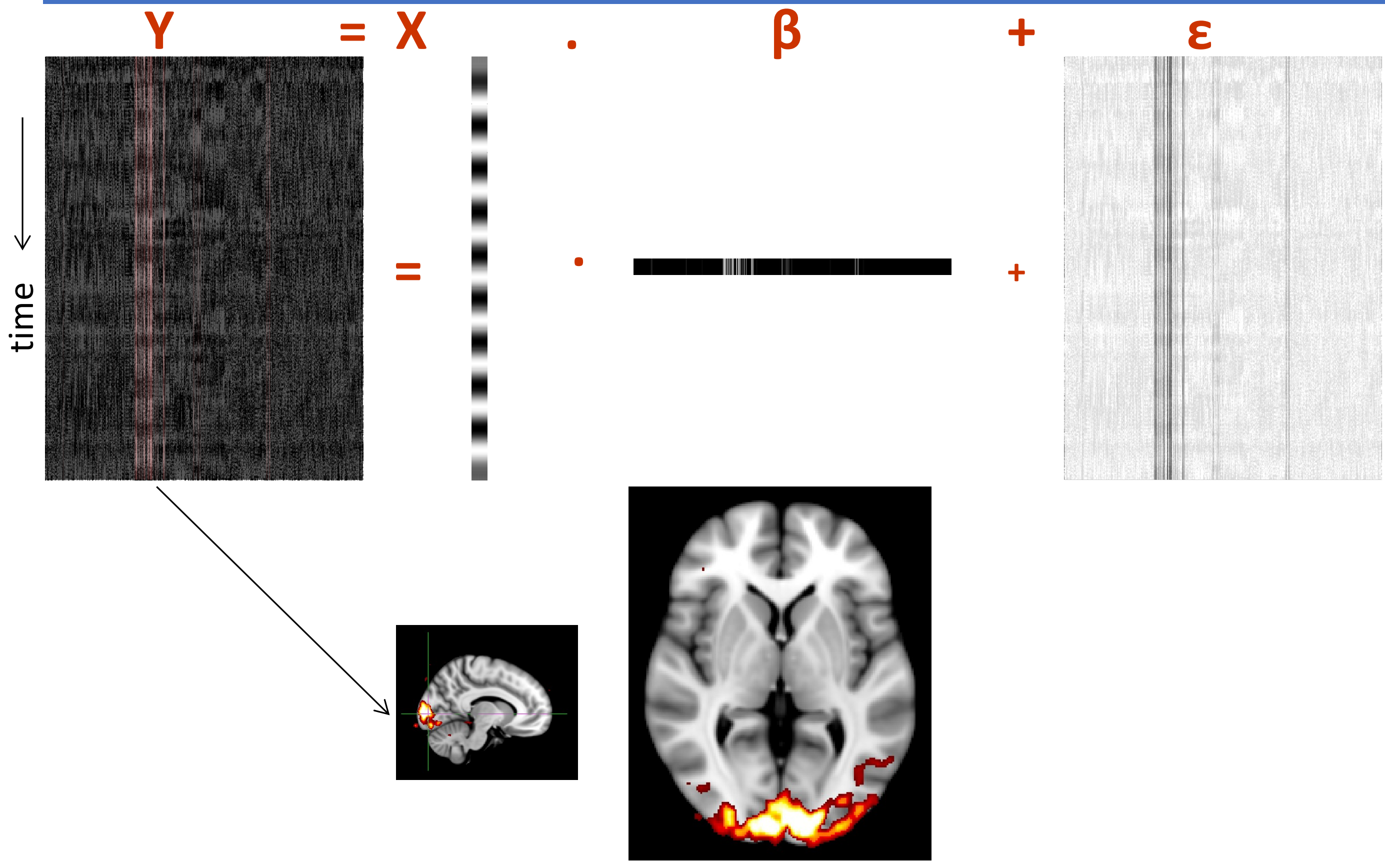
General Linear Model(GLM)



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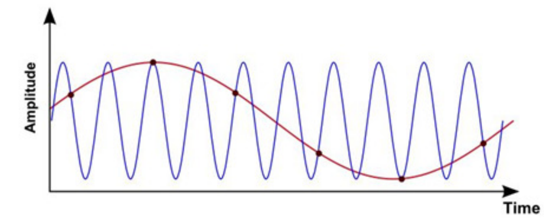
How to denoise fMRI data?

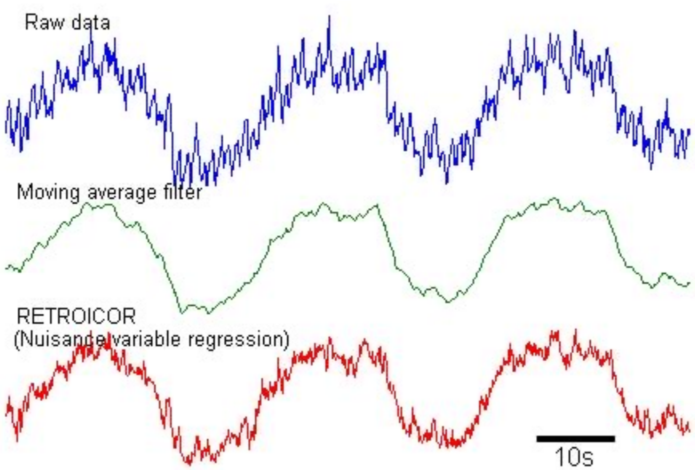
Moving average filter (Lin et al., 2011; Posse et al., 2012)

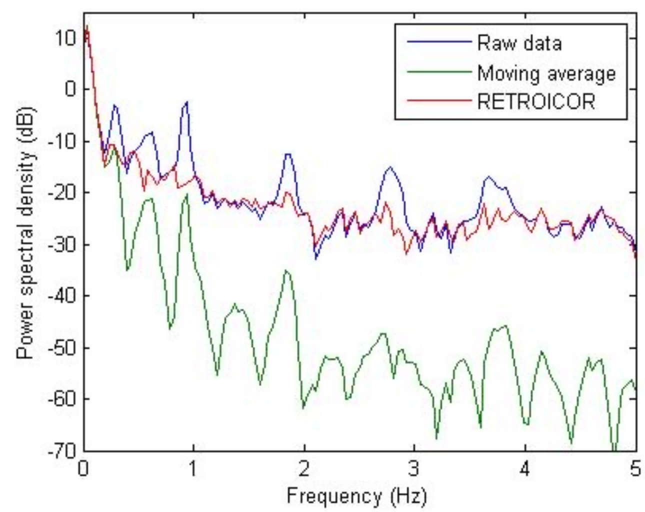
Removes high frequencies and affects noise properties

Artefact modeling (Glover et al., 2000; Lund et al., 2006)

Model noise as high-order autoregressive process







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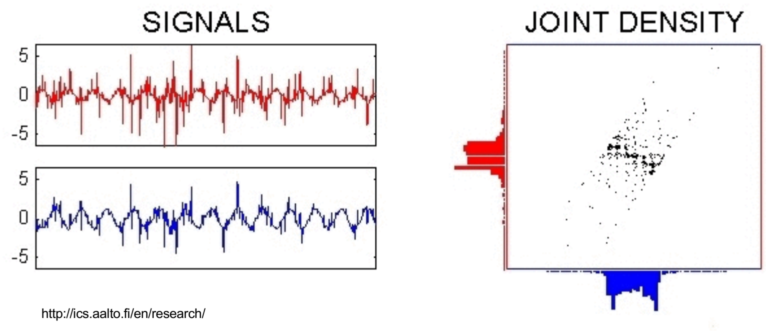
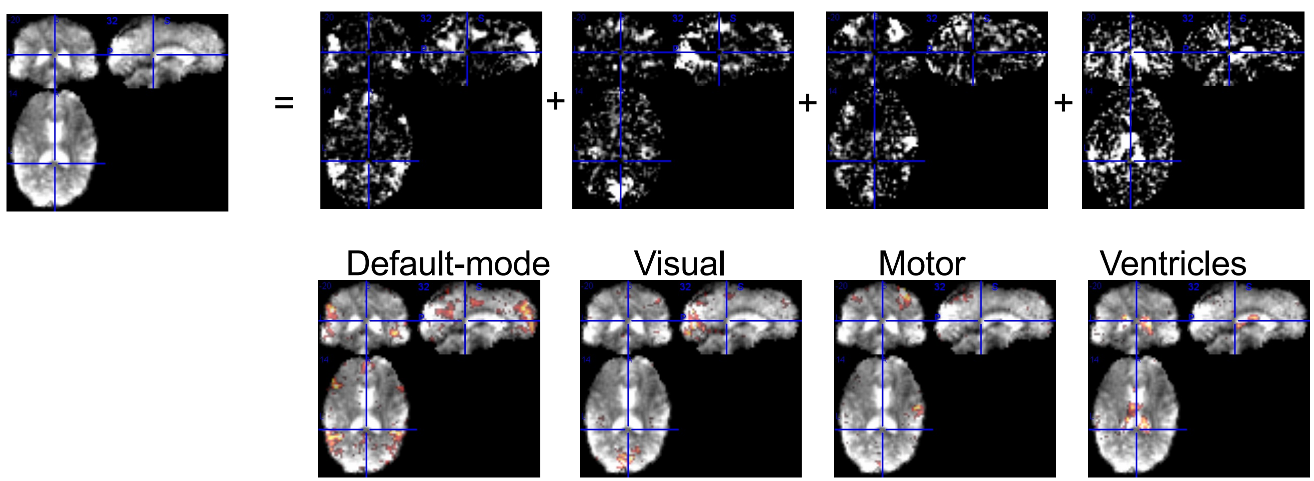
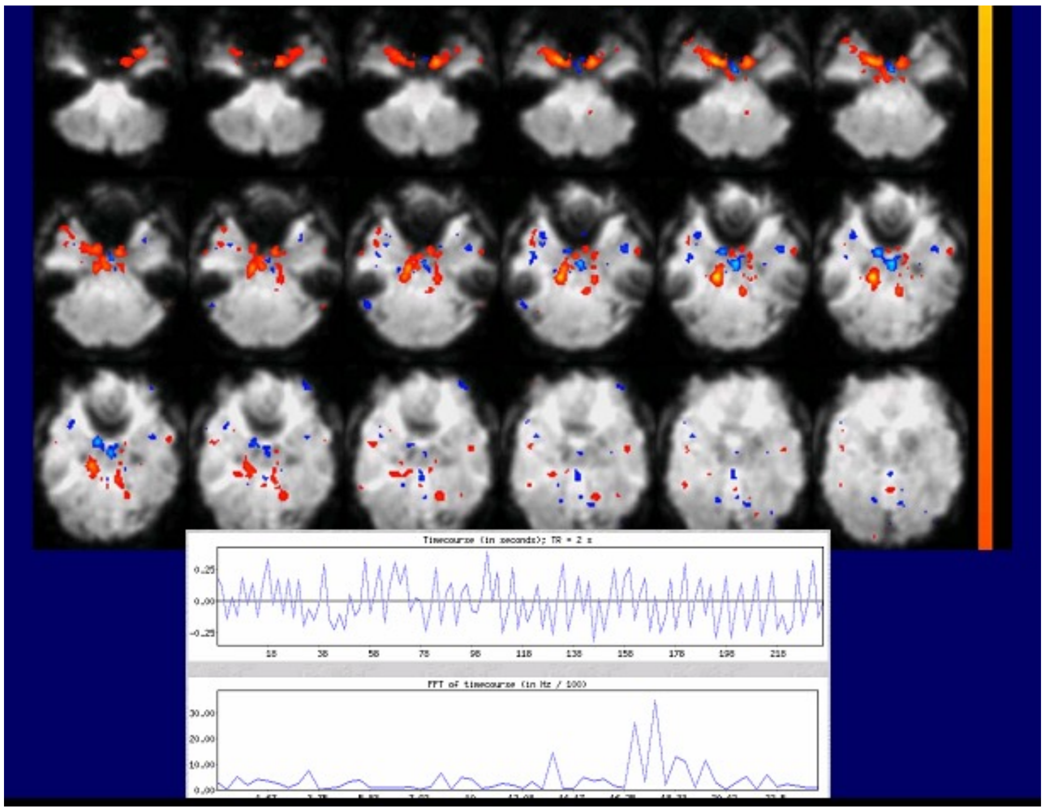
Independent Component Analysis

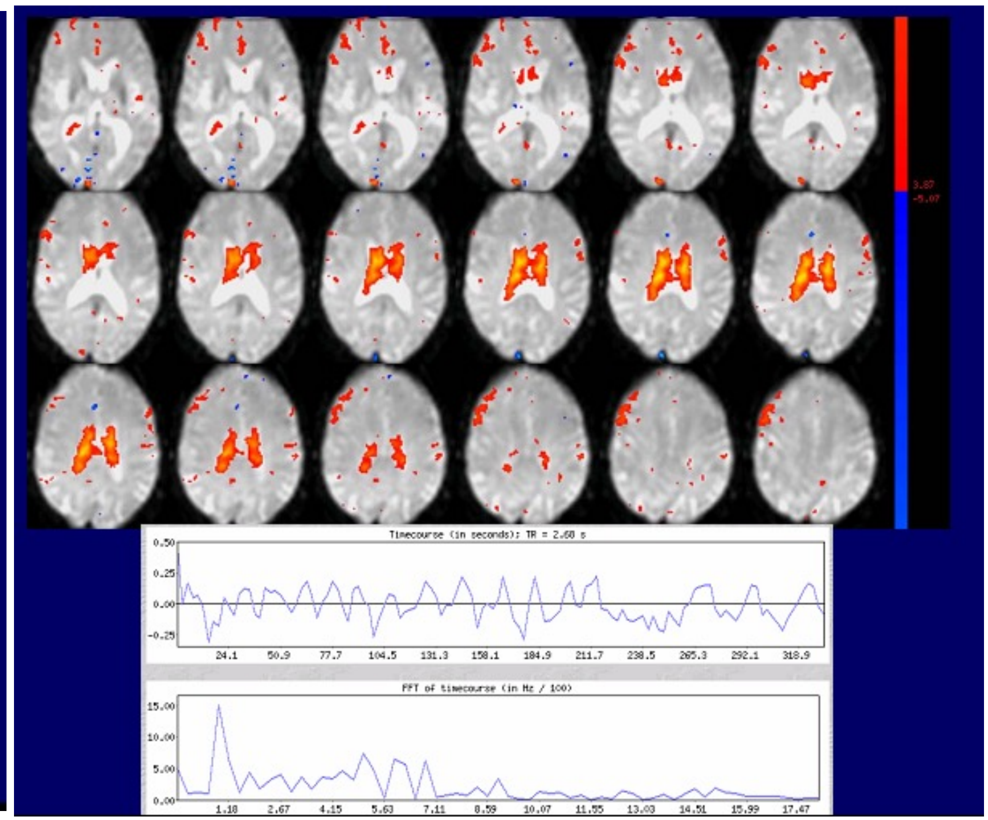
- ICA is the mathematical approach that performs this so-called “blind source separation”
- In fMRI: at each time point, we measure a mixture of unknown functional networks (as well as artifacts)
- Networks fluctuate and are thus mixed differently at each time point



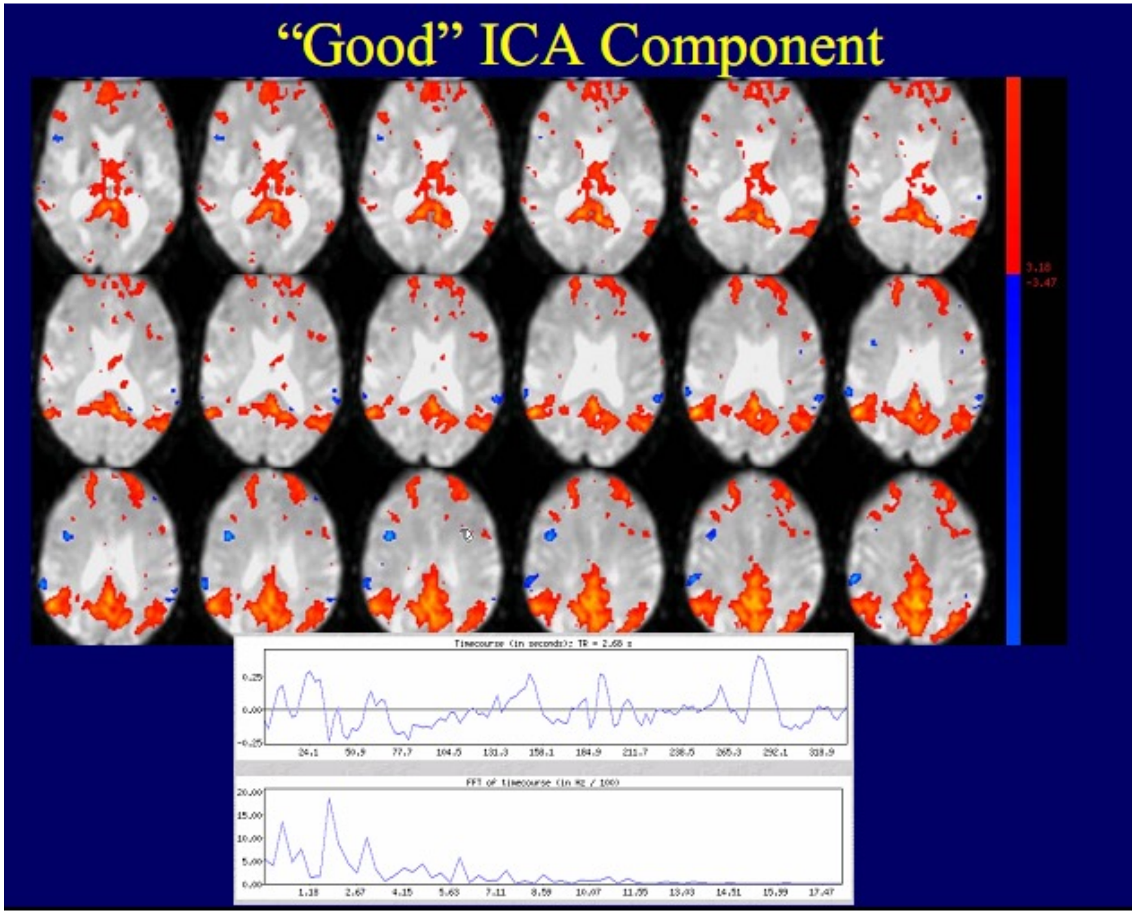


Bad components?

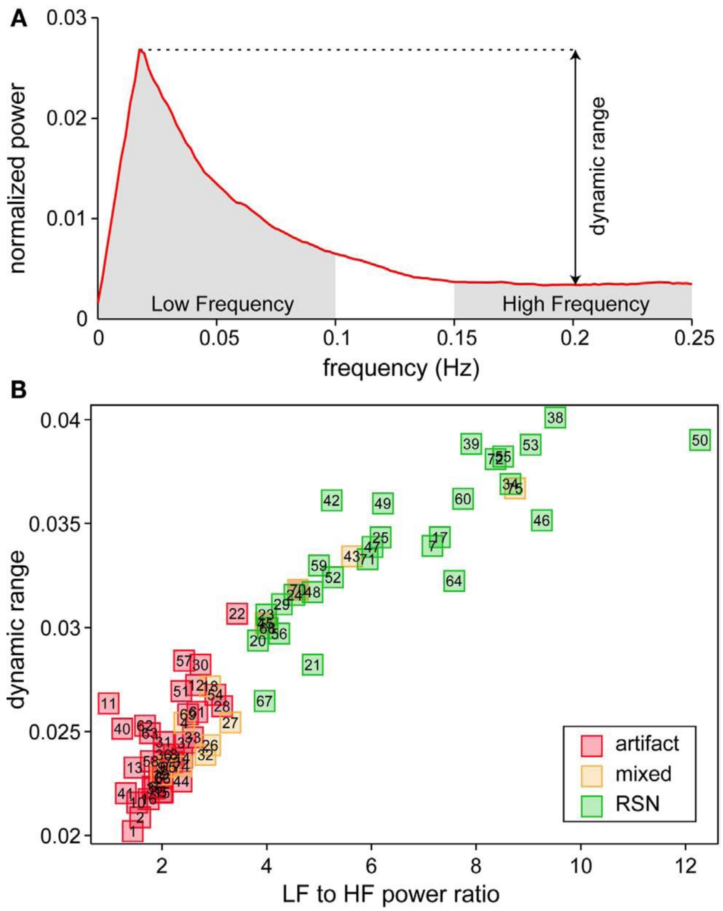




Good components?



How to denoise fMRI data?

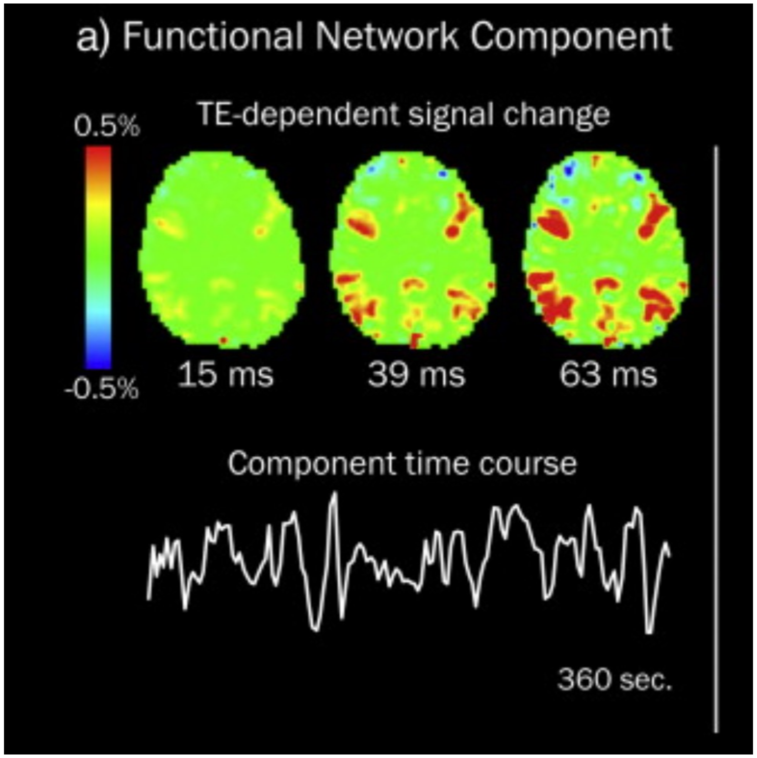


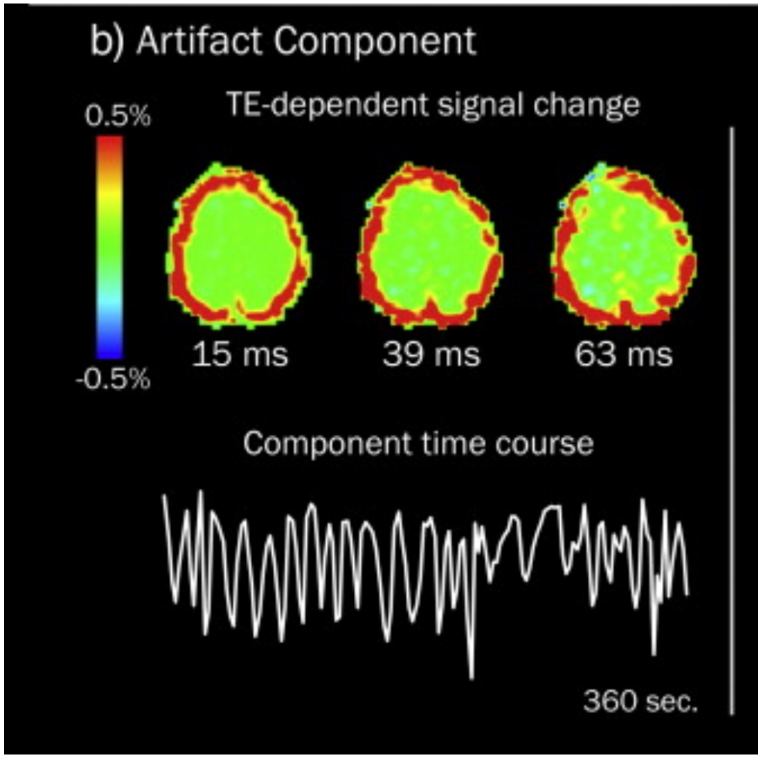
fALFF

fractional amplitude of lowfrequency fluctuations

summing the oscillatory amplitudes across the typical 0.01-0.08 Hz range, then dividing by the amplitude sum across 0-0.25 Hz

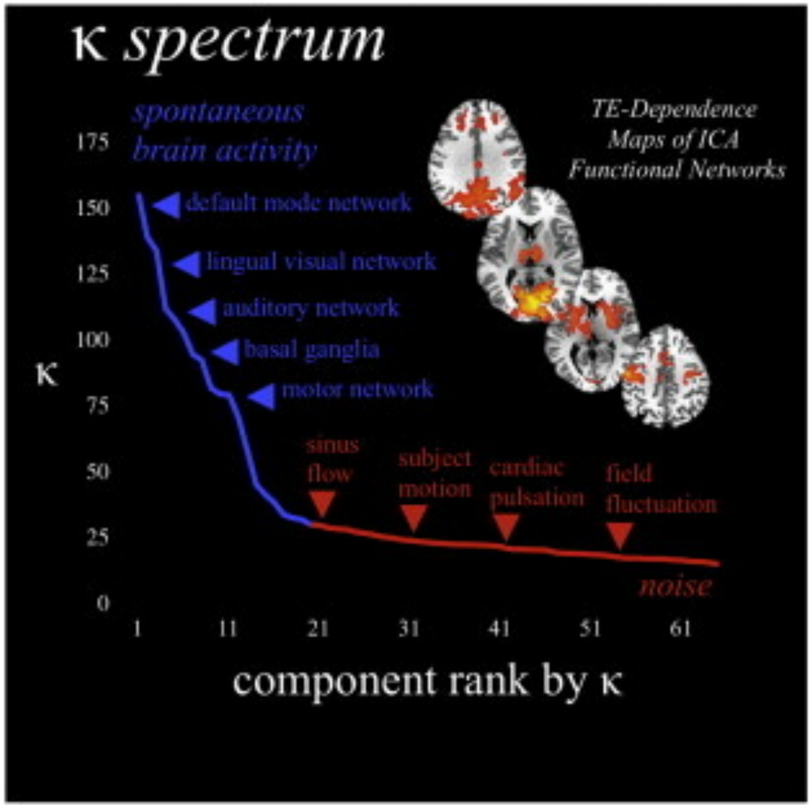
Multi-Echo EPI

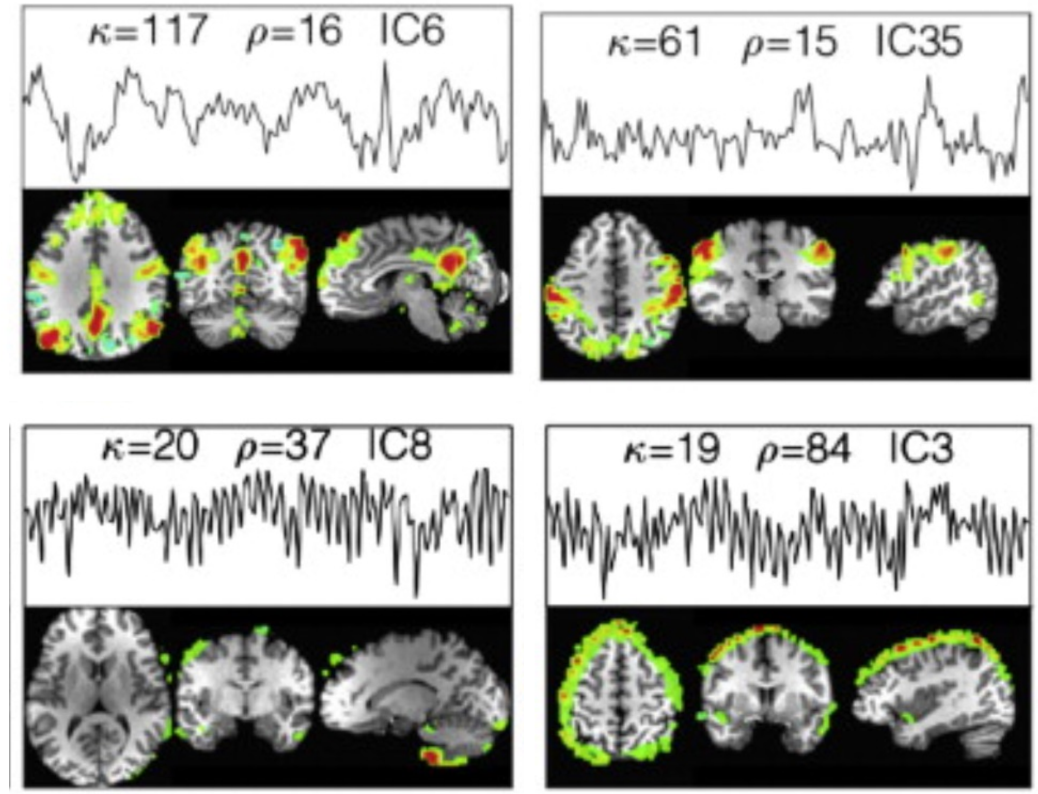




Kundu et, al.2012

Multi-Echo EPI





Kundu et, al.2012

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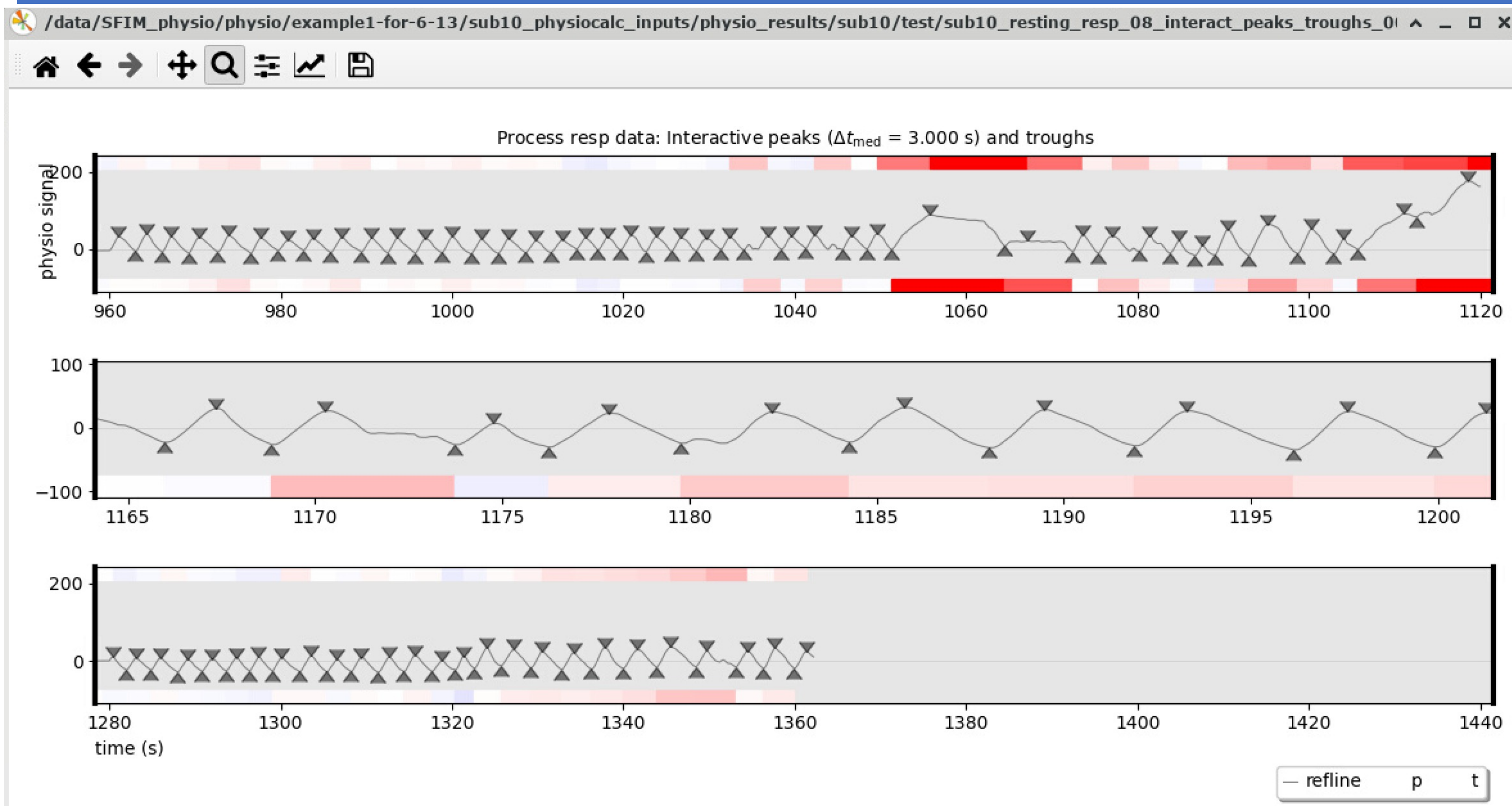
AFNI physio_calc.py

```
physio_calc.py                                                              \
       -card_file          sub-001_ses-01_task-rest_run-1_physio-ECG.txt   \
       -resp_file          sub-001_ses-01_task-rest_run-1_physio-Resp.txt  \
       -freq               500                                              \
       -dset_tr            0.1                                              \
       -dset_nt            219                                              \
       -dset_nslice        33                                               \
```

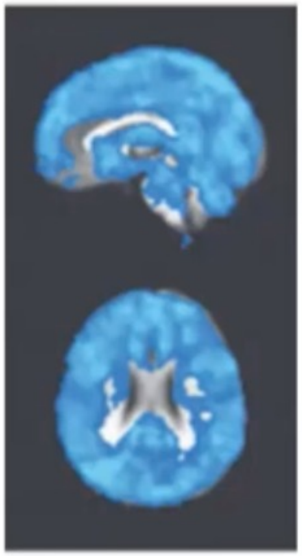
```
afni_proc.py -subj_id bp10 \
             -blocks tcat despike tshift align tlrc volreg mask scale regress \
             -radial_correlate_blocks tcat volreg \
             -copy_anat /data/akinb2/allbp/bp10/anat/anatSS.bp10.nii \
             -anat_has_skull no \
             -anat_follower_ROI aaseg  anat /data/akinb2/allbp/fsurfs/bp10/SUMA/aparc.a2009s+aseg.nii.gz \
             -anat_follower_ROI aeseg  epi  /data/akinb2/allbp/fsurfs/bp10/SUMA/aparc.a2009s+aseg.nii.gz \
             -tcat_remove_first_trs 0                                                                    \
             -dsets /data/akinb2/allbp/bp10/rest.nii \
```

AFNI physio_calc.py

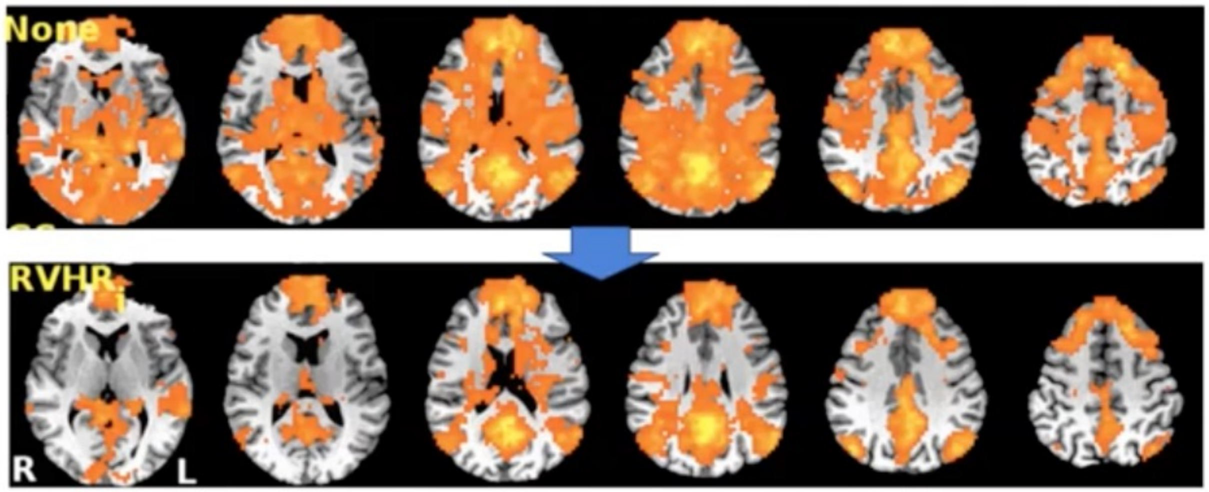


RVT

Higher functional connectivity (PCC seed) without RVT correction



RVTcor



Falahpour et al., Neuroimage 2013; 72: 252

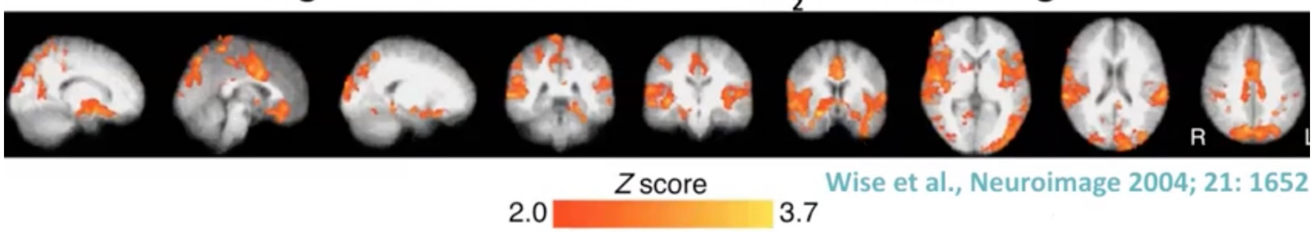
Birn et al. Brain Connectivity 2014; 4: 511

RVT

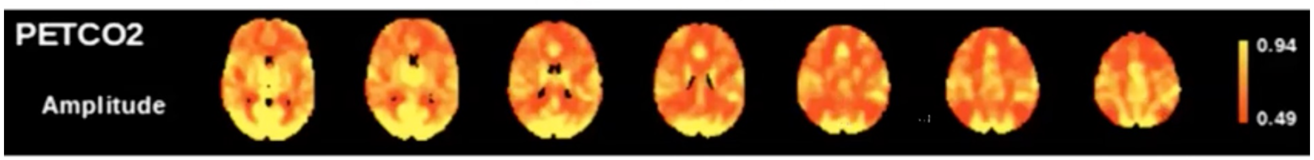
Regions related to end-tidal CO_2

- The contributions by RVT and CO_2 only partially overlap[1,2]
- CO_2 fluctuations produce network patterns that mimic functional networks[3]

Strength of association between CO_2 and rs-fMRI signal



Wise et al., Neuroimage 2004; 21: 1652



Golestani et al., Neuroimage 2015; 104: 266

1. Chang et al. Neuroimage 2009; 47: 1381
2. Golestani et al., Neuroimage 2015; 104: 266
3. Bright et al., Neuroimage 2020; 116970

Neuroimage. 2020 Aug 15:217:116907. doi: 10.1016/j.neuroimage.2020.116907. Epub 2020 May 6.

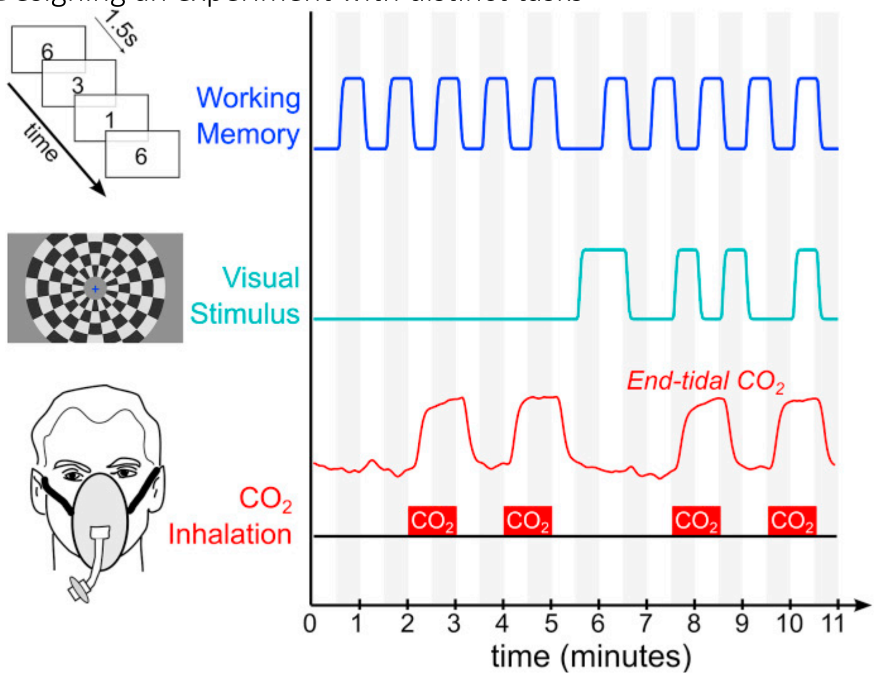
Vascular physiology drives functional brain networks

Molly G Bright [1], Joseph R Whittaker [2], Ian D Driver [3], Kevin Murphy [2]

Affiliations + expand

PMID: 32387624 PMCID: PMC7339138 DOI: 10.1016/j.neuroimage.2020.116907

Designing an experiment with distinct tasks



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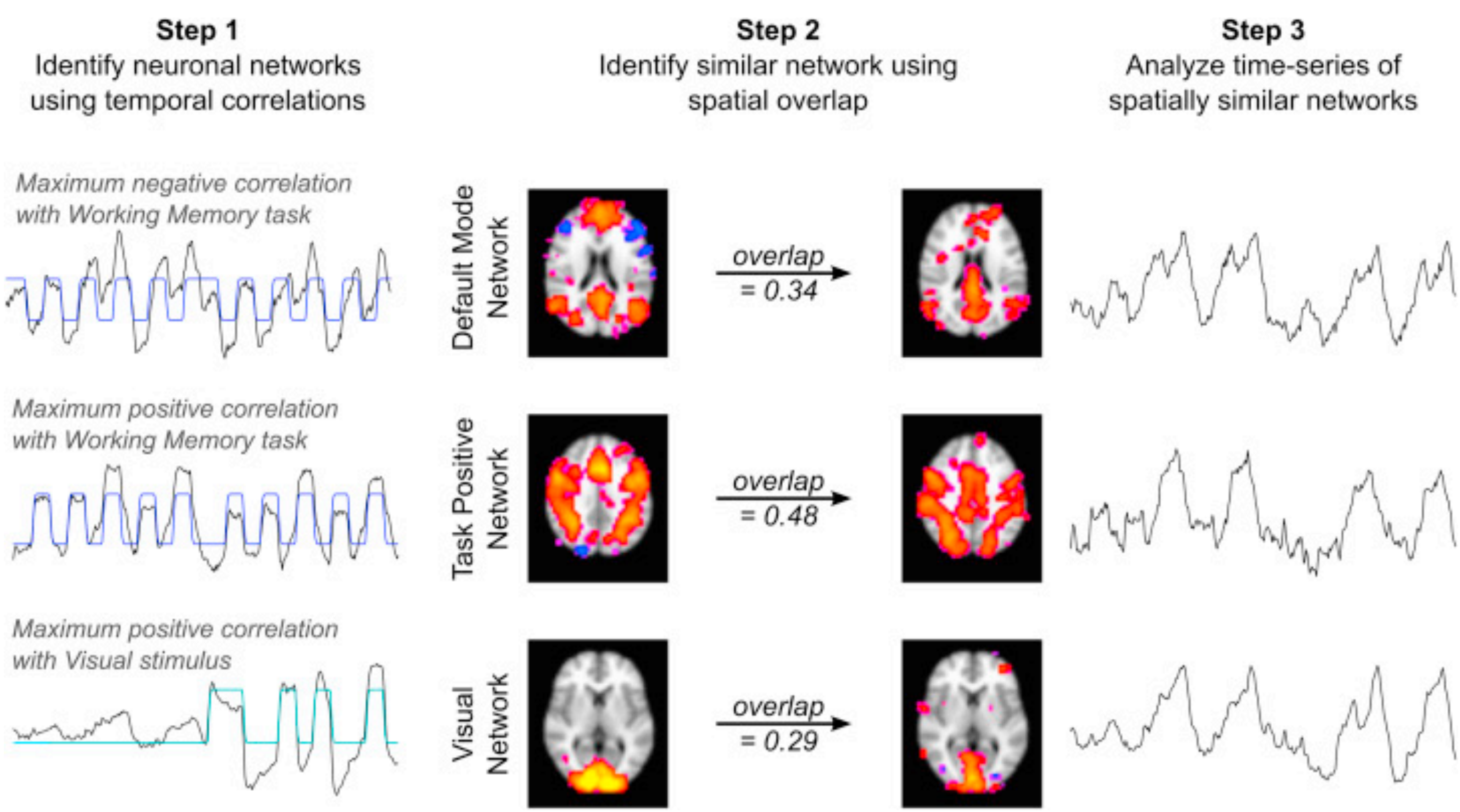
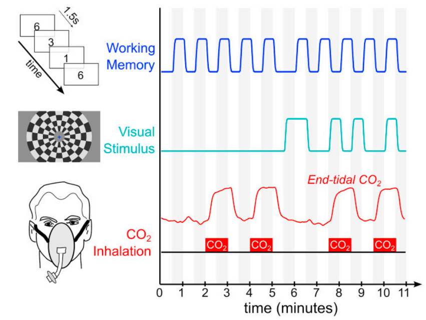
Designing an experiment with distinct tasks





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Some take home messages

- Always look at your data
- Always acquire physiology
- Physiological confounds might be both noise or signal
- Design a task paradigm that helps to disentangle sources of signals
- Design a processing pipeline that helps to delineate the activity

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Thanks for your attention!