Volumetric Space–Time Structure of Physiological Noise in BOLD fMRI

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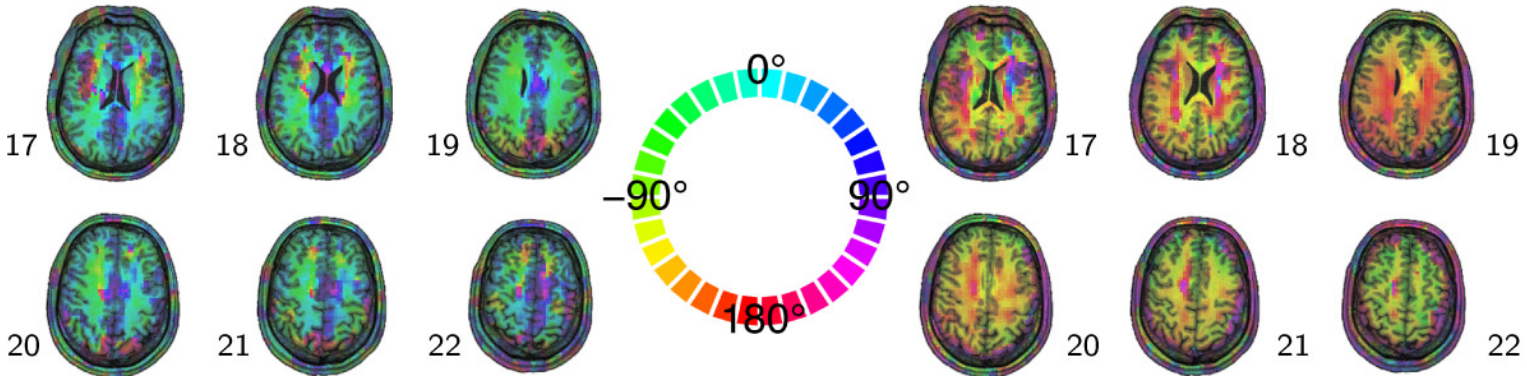

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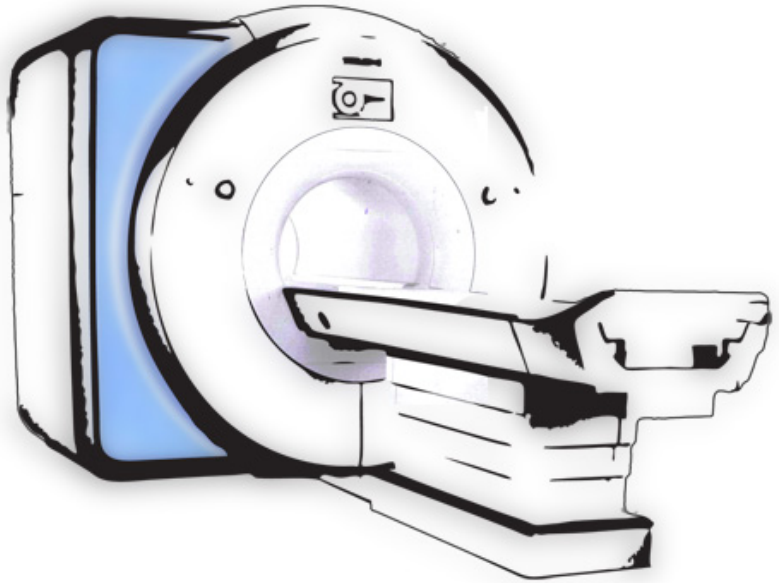
Aims of Study

- Estimate volumetric **amplitude and latency maps** of physiological noise in the brain.
- Determine the **strength** and relative **phase shift** compared to an external physiological reference signal.

- The results can be:
  - Used in **studying the structure** of physiological noise in the brain.
  - Applied to removal or **estimation of noise components** in slow fMRI.
  - Utilized in future fast-**imaging techniques** as *a priori* information.

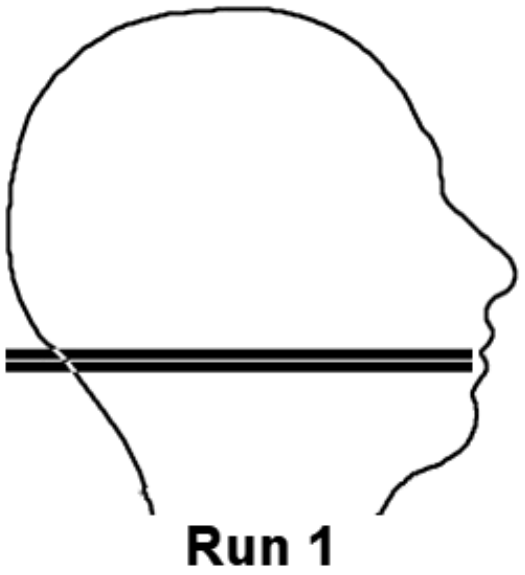
Data Acquisition

- A **27-run set** of resting state fMRI data and **anatomical images** for **one volunteer**.
- Sequence parameters:
  - 3 T scanner (*Siemens Skyra*)
  - TR: 77 ms
  - TE: 21 ms
  - FA: 60 degrees
  - FOV: 224 mm
  - Matrix size: 64x64
  - Voxel size: 3.5x3.5x6 mm

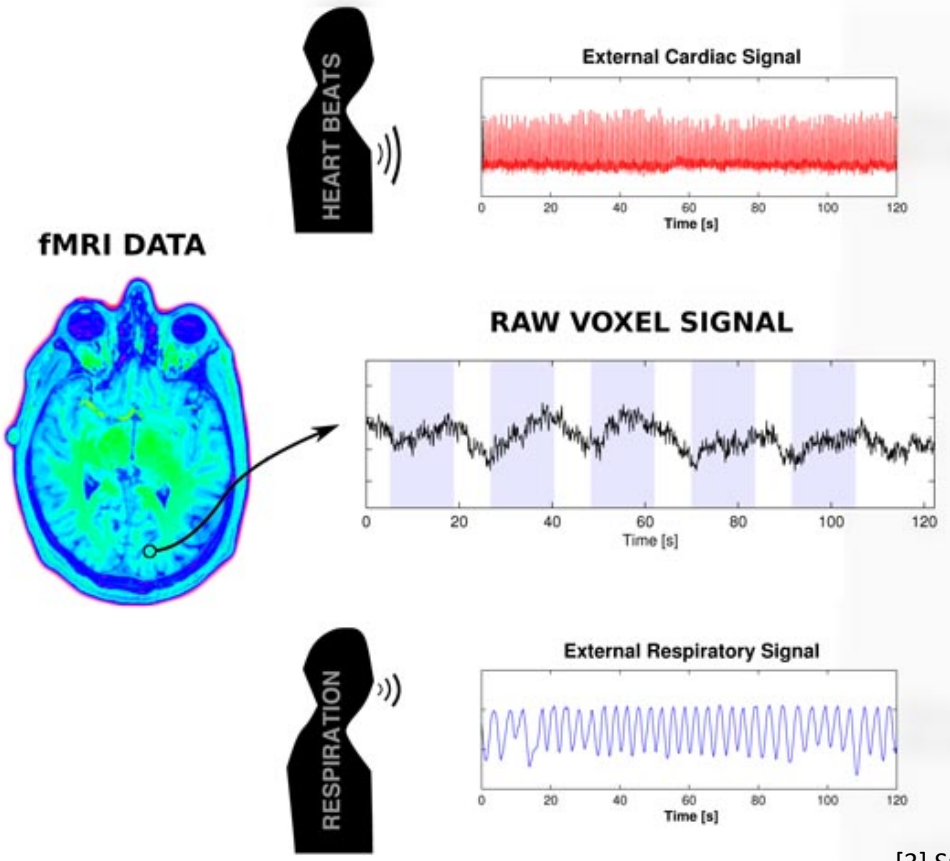


Data Acquisition

- Each run, roughly **30 s in length**, comprised of **two slices**:
  - One fixed reference slice
  - Gap size between the slices advancing with run number
- The reference slices were used for validation.
- **Cardiac and respiration reference signals** were acquired time-locked to the fMRI.



Finding Physiological Signals

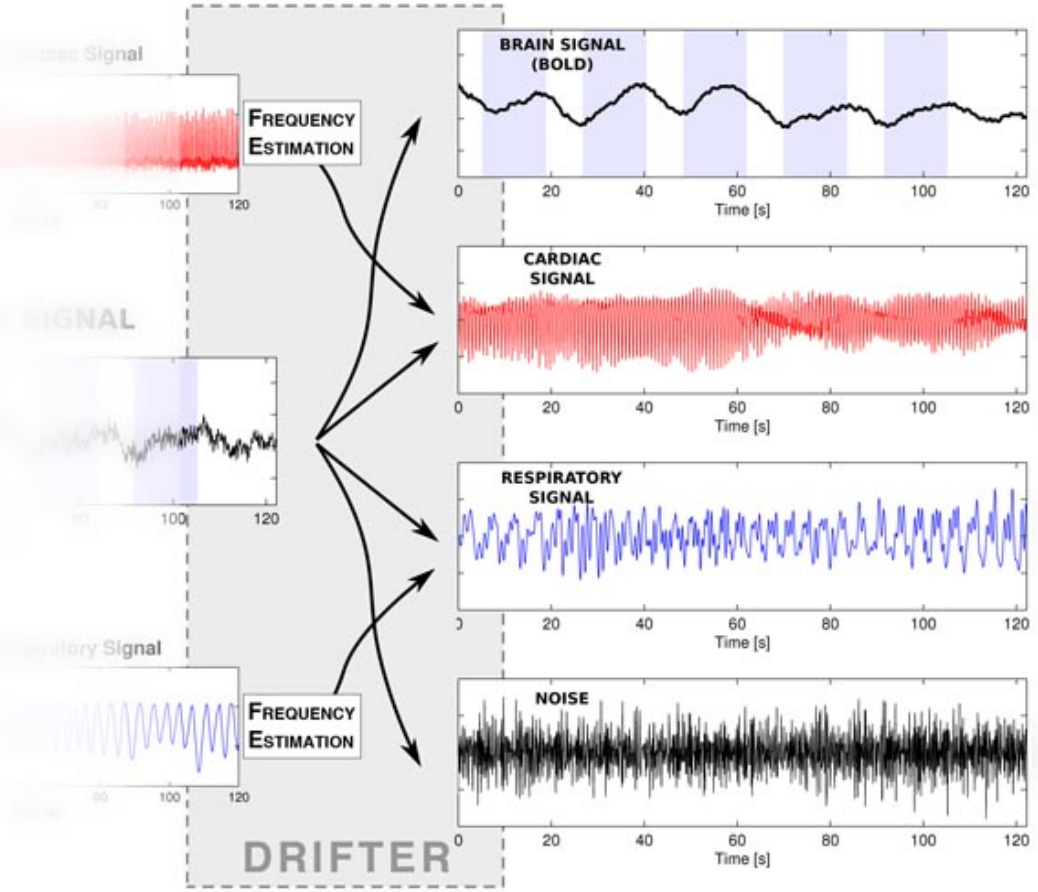


- We use the **DRIFTER** algorithm [3] for separating the oscillating signals from the fMRI data.
- Voxel time series and external reference signals as inputs.
- The method is based on modeling stochastic oscillators with Kalman filters.
- Open source Matlab **toolbox available** online.

[3] Särkkä S., *et al.* Dynamical retrospective filtering of physiological noise in BOLD fMRI: DRIFTER. *NeuroImage*. 2012;60:1517–1527.

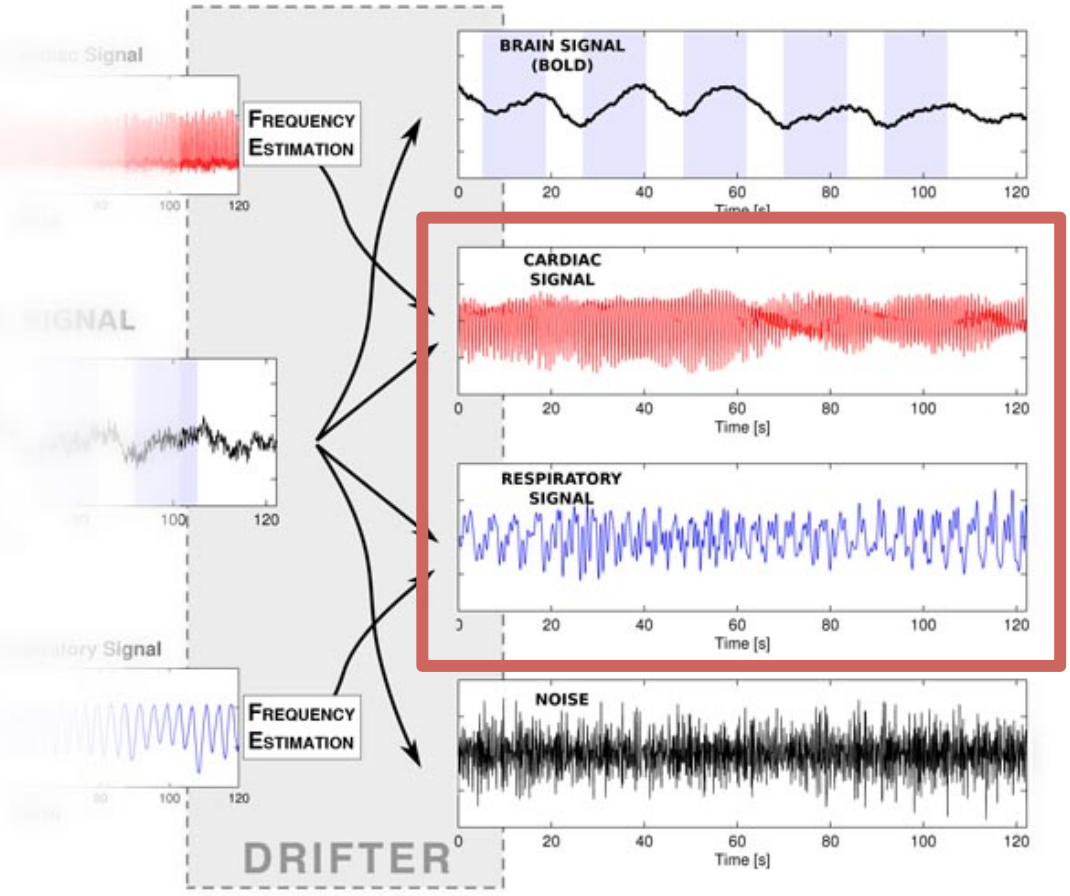
Finding Physiological Signals

- DRIFTER separates the original voxel time series into components.
- Lowest frequency components of the oscillators are converted into analytic signals.



Estimation of Amplitude and Latency

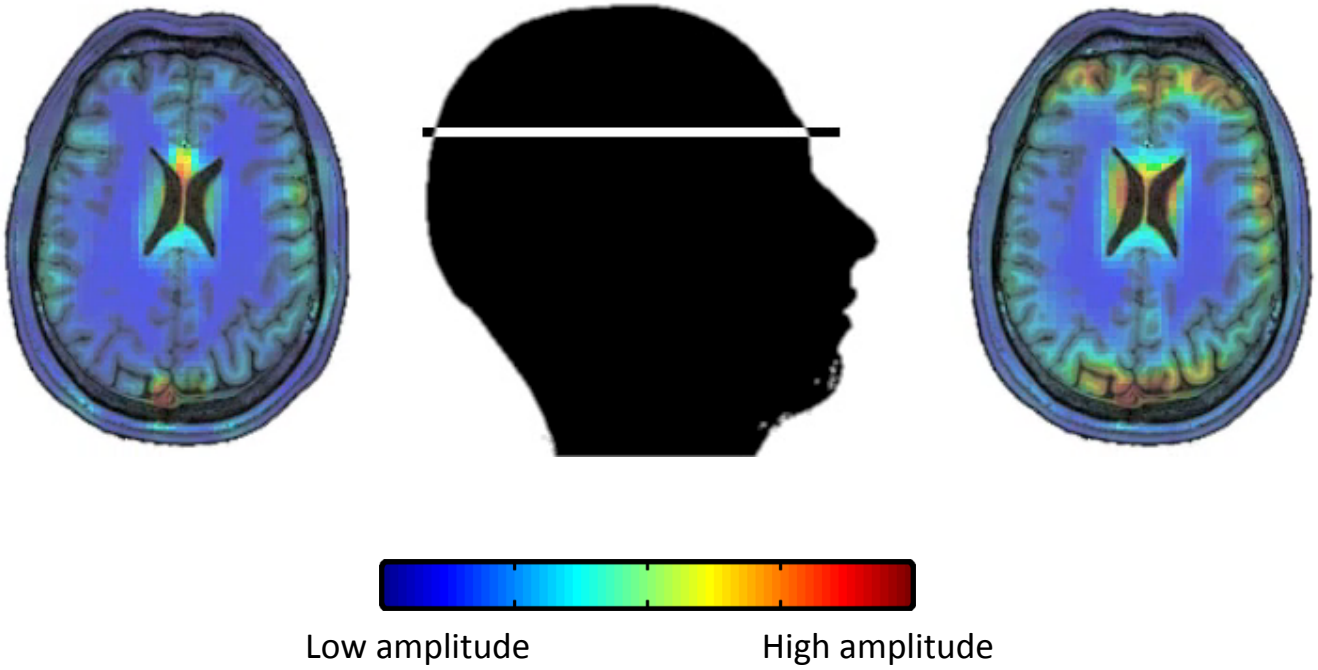
- Spatial regularization is applied in form of a Gaussian smoothing filter.
- Phase differences between the analytic signals and the external references.
- Studied in terms of complex polar coordinates.
- Visualized as magnitude and phase images.



Volumetric Amplitude Maps

Cardiac Amplitude

Respiratory Amplitude

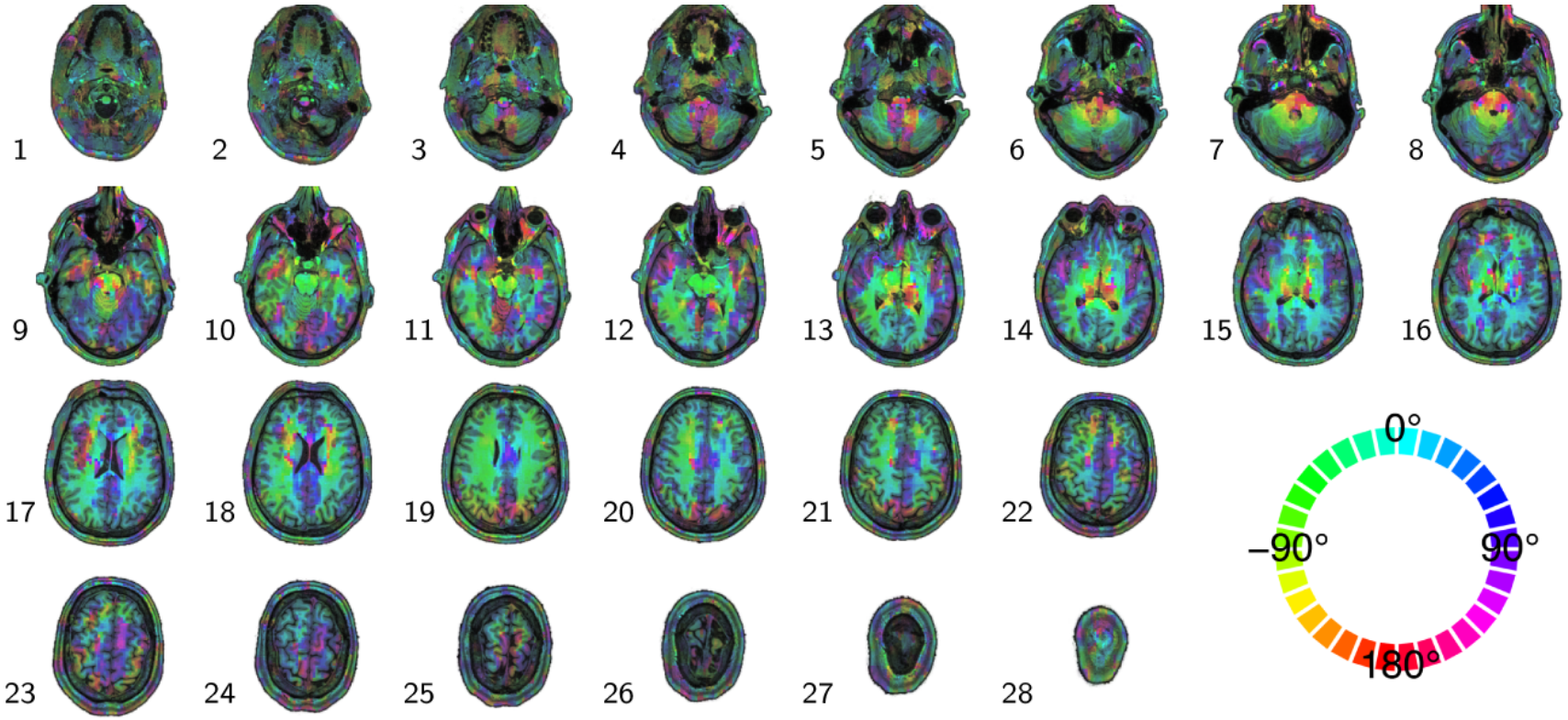


Low amplitude

High amplitude

Volumetric Cardiac Phase/Latency

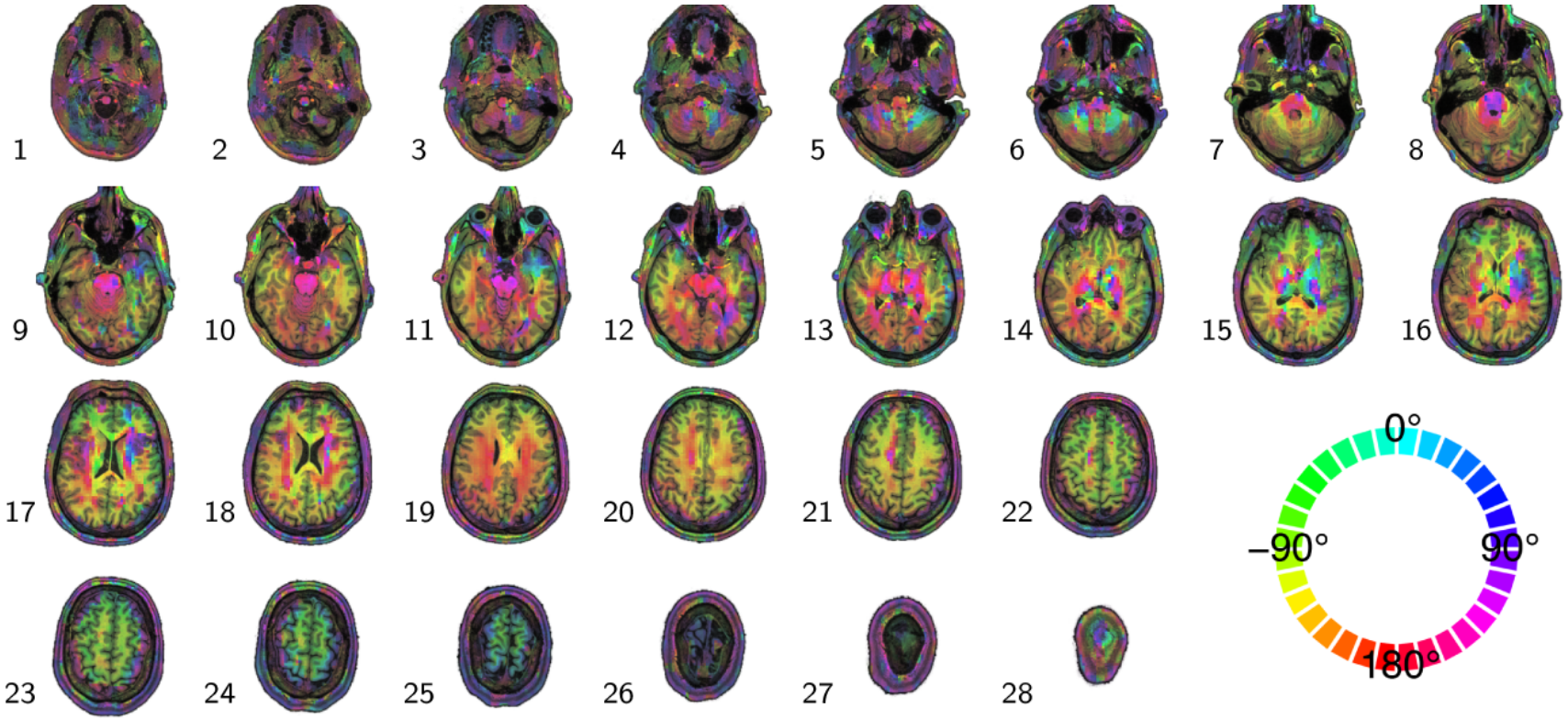
A full cycle corresponds to a lag of approximately 0.94 s.



Similar colors indicate small phase difference / low latency.

Volumetric Respiratory Phase/Latency

A full cycle corresponds to a lag of approximately 4.2 s.



Similar colors indicate small phase difference / low latency.

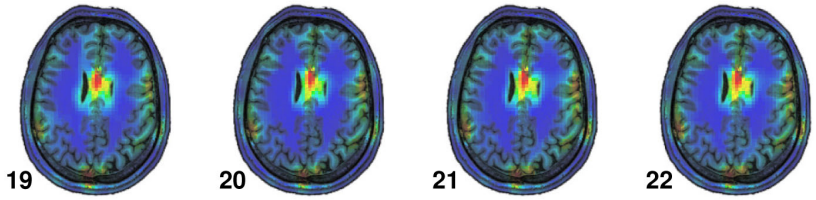
Discussion

Interpretation:

- Clear phase shift between different areas in the oscillatory noise signals.
- The cardiac phase is nearly constant over the cerebral cortex.
- The respiratory phase follows a more uniform pattern over the whole volume.

Validation:

- The reference slices were used to confirm that the approach provides useful estimates.
- Below four independent respiratory amplitude estimates for slice number 19.
  - ➢ The estimates are very similar



Discussion

Practical implications:

- Phase shifts 0^o, 90^o, and 180^o imply correlations 1, 0, and -1, which has effect to **connectivity analysis**.
- These temporal phase maps can be provided by a reference scan or they can be pre-calculated.

Future Research:

- Combine the *a priori* phase and slice timing information for finding physiological noise in slow EPI.
- Structural information can be used as *a priori* information in **ultra-fast parallel imaging** methods.

Conclusion

- We have presented means to **estimate the volumetric spatio-temporal structure** of oscillating physiological signals in BOLD fMRI.
- Phase shift maps can provide substantial prior information in **noise elimination** and **image reconstruction** methods.

The **DRIFTER toolbox** for Matlab/SPM 8
is available for download at:
http://becs.aalto.fi/en/research/bayes/drifter/