Volumetric Space–Time Structure of Physiological Noise in BOLD fMRI

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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.

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 $0^\circ$, $90^\circ$, and $180^\circ$ 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/