Principles of fMRI

Part I

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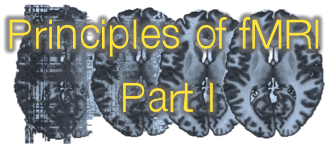
fMRI Artifacts & Noise

fMRI Noise

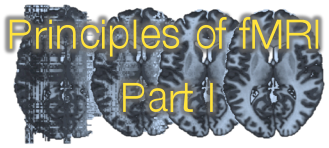


- BOLD fMRI signal contains multiple sources of noise related to the hardware and the participants themselves.

- Sources of noise:
  - Thermal motion of free electrons in the system
  - Gradient and magnetic field instability
  - Head movement and its interactions with magnetic field
  - Physiological effects, including heartbeat and respiration

- Appears in data as:
  - High-frequency ‘spikes’
  - Image artifacts and distortions
  - Low-frequency (slow) drift and periodic fluctuation over time

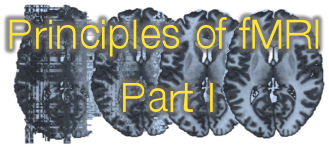
Noise and artifact mitigation



- Acquisition:
  - Good quality control processes for scanner
  - Choose acquisition sequence/parameters for your goal
  - Specialized sequences (e.g., spin-echo, simultaneous multi-slice, z-shimming).
  - Minimize head movement

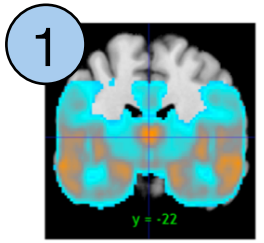
- Analysis:
  - Look at data as it is acquired to check for issues
  - Outlier / artifact identification and correction
  - Preprocessing to adjust for head movement, drift
  - Helpful statistical procedures (e.g., robust regression, hierarchical modeling)
  - Low-frequency (slow) drift and periodic fluctuation over time

Acquisition artifacts: Look at your data!

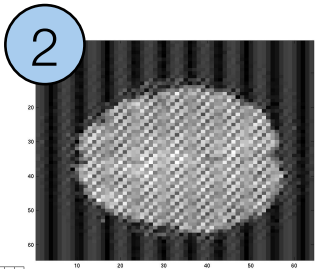


- Five issues you should check for and avoid

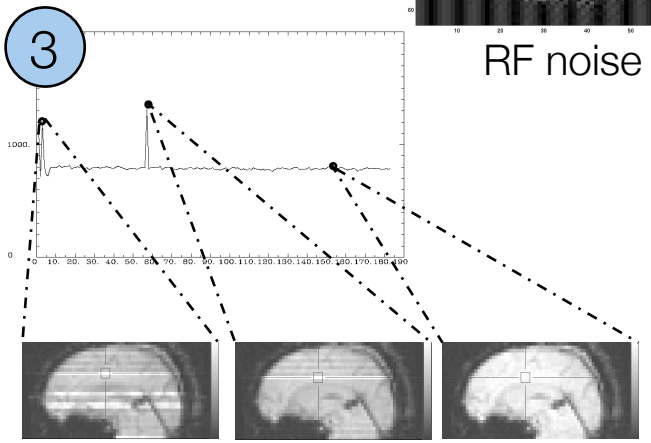
1. Coverage not what you intended
2. RF noise and malformed images
3. Transient gradient artifacts/spikes
4. Ghosting
5. Susceptibility artifacts/dropout
6. Task-correlated head movement



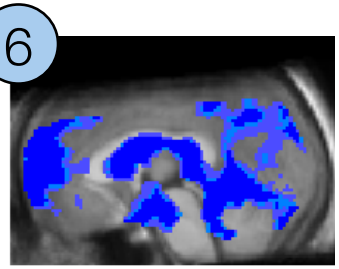
Coverage

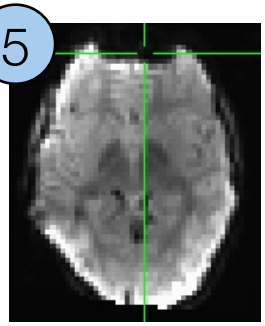


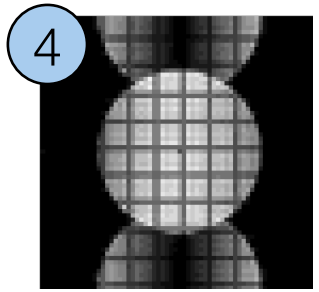
RF noise



Task-correlated movement



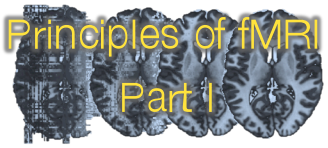




Ghosting

Ghosting image courtesy of Luis Hernandez-Garcia

Acquisition artifacts: Look at your data!



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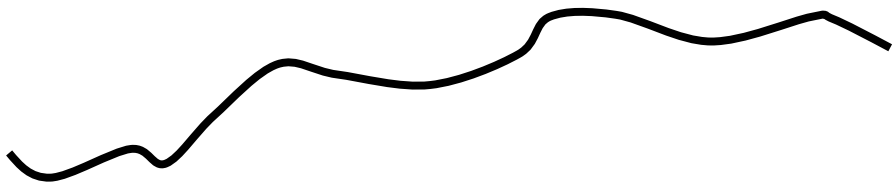
- All fMRI data contain some artifacts
- It is very difficult to deal with bad artifacts during analysis
- Try to avoid them during acquisition

Drift

- Slow changes in voxel intensity over time (low-frequency noise) is present in the fMRI signal.

- Scanner instabilities are a main cause of drift, as drift has been seen in cadavers, but aliased physiological noise is also important.

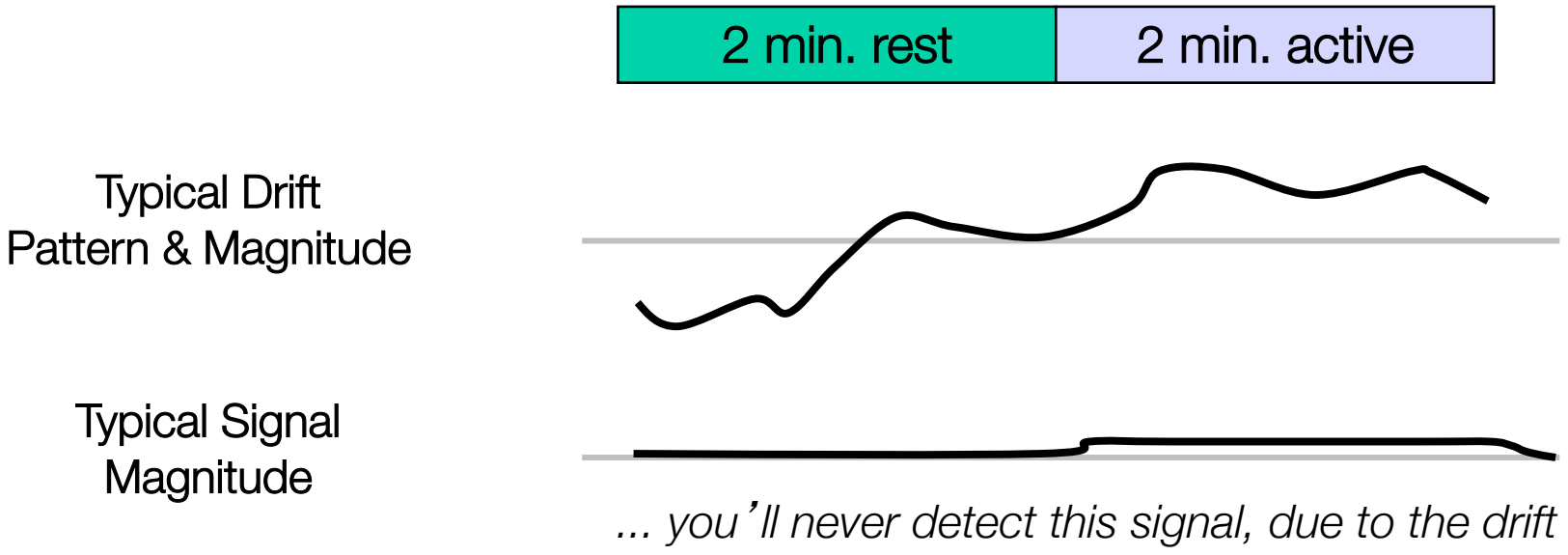
- We need to account for drift both in preprocessing and when we conduct statistical analyses.



Issues

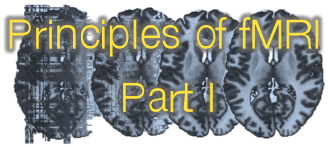
- Drift can have serious consequences:
  - Experimental conditions that vary slowly may be confused with drift.
  - Experimental designs should use high frequencies (more rapid alternations of stimulus on/off states).

- Bad Design:



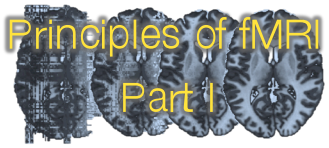
... you'll never detect this signal, due to the drift

Motion



- Subject motion during the experiment can also give rise to serious problems.
- Typically motion correction is performed in the pre-processing stages of the analysis.
- However, ‘spin-history’ artifacts may remain that cannot be removed.
  - This is caused in part by through-plane motion and complex interactions with the magnetic field
  - Attempts to account for it are often made in during statistical analysis, but these are imperfect.

Physiological Noise



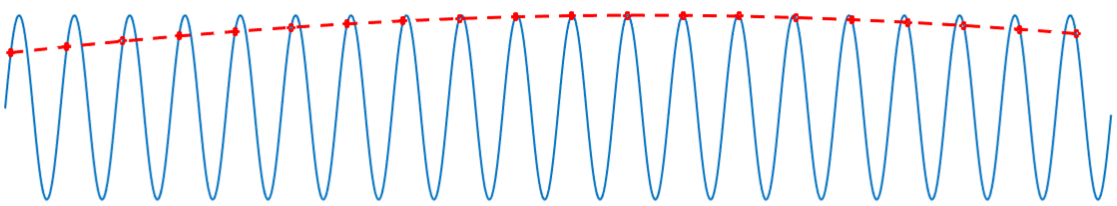
- Respiration and heart beat give rise to noise at particular frequencies.

- It can potentially be modeled in statistical analysis, but if the TR is too low there will be problems with *aliasing*.

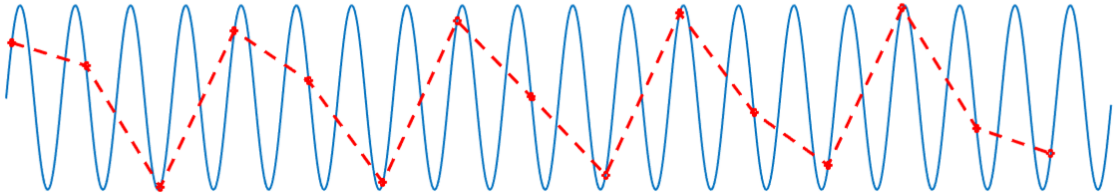
- For standard TR values (~ 2s) this type of noise is difficult to remove and is often left in the data giving rise to temporal autocorrelations.

Aliasing

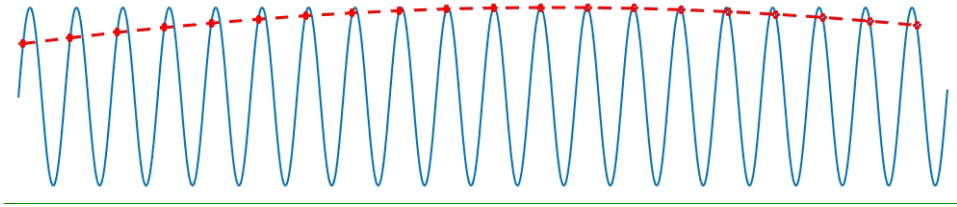
- Periodic signals that occur more rapidly than the sampling rate will often be *aliased* back to lower frequencies.



Signal (blue) sampled at near its periodicity. Observed signal is aliased, close to the 'fundamental frequency' (flat line).

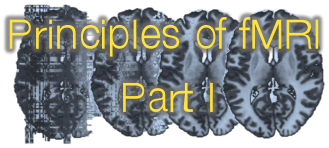


Another example: Sampling at about ½ the original frequency results in aliased periodicity about ¼ the original frequency.



Signals faster than ½ the sampling rate—called the Nyquist frequency—will be aliased. To avoid aliasing, you must sample at least twice as fast as the fastest frequency in your signal.

Modeling fMRI Noise



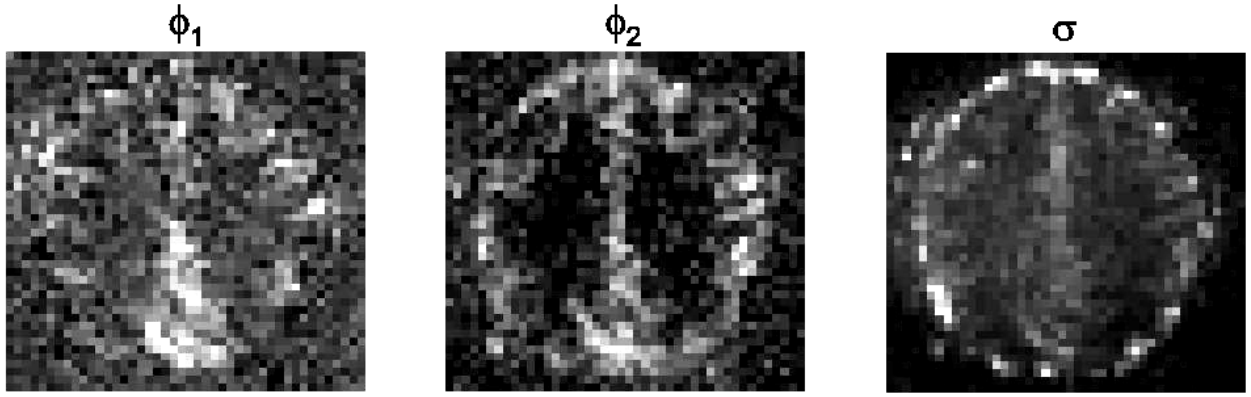
- Some noise components can be removed prior to or during analysis, including low-frequency drift and images identified as outliers.

- However, it is impossible to remove or model all sources of noise, and therefore significant autocorrelation (non-independence of the observations over time) is usually present in the signal.

- In fMRI we typically use autoregressive (AR) or autoregressive moving-average (ARMA) processes to model the autocorrelation.

Spatio-temporal Behavior

- The spatiotemporal behavior of these noise processes is complex.



Spatial maps of the model parameters from an AR(2) model estimated for each voxel's noise data.

End of Module

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