Fundamentals of the analysis of neuronal oscillations

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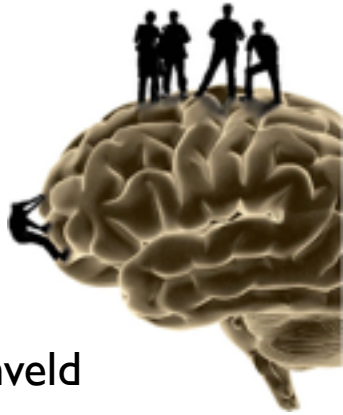


based on slides from Robert Oostenveld

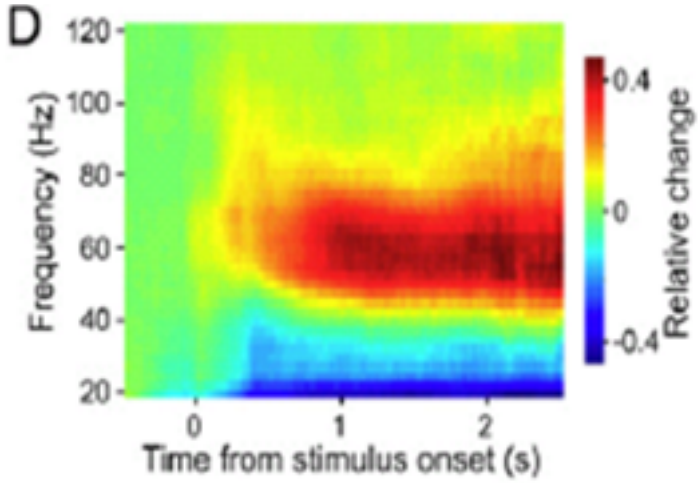
Separating sources

- Use the temporal aspects of the data at the channel level
  - ERF latencies
  - ERF difference waves
  - Filtering the time-series
  - Spectral decomposition
- Use the spatial aspects of the data

Brain signals contain oscillatory activity at multiple frequencies

Cohen, 1972

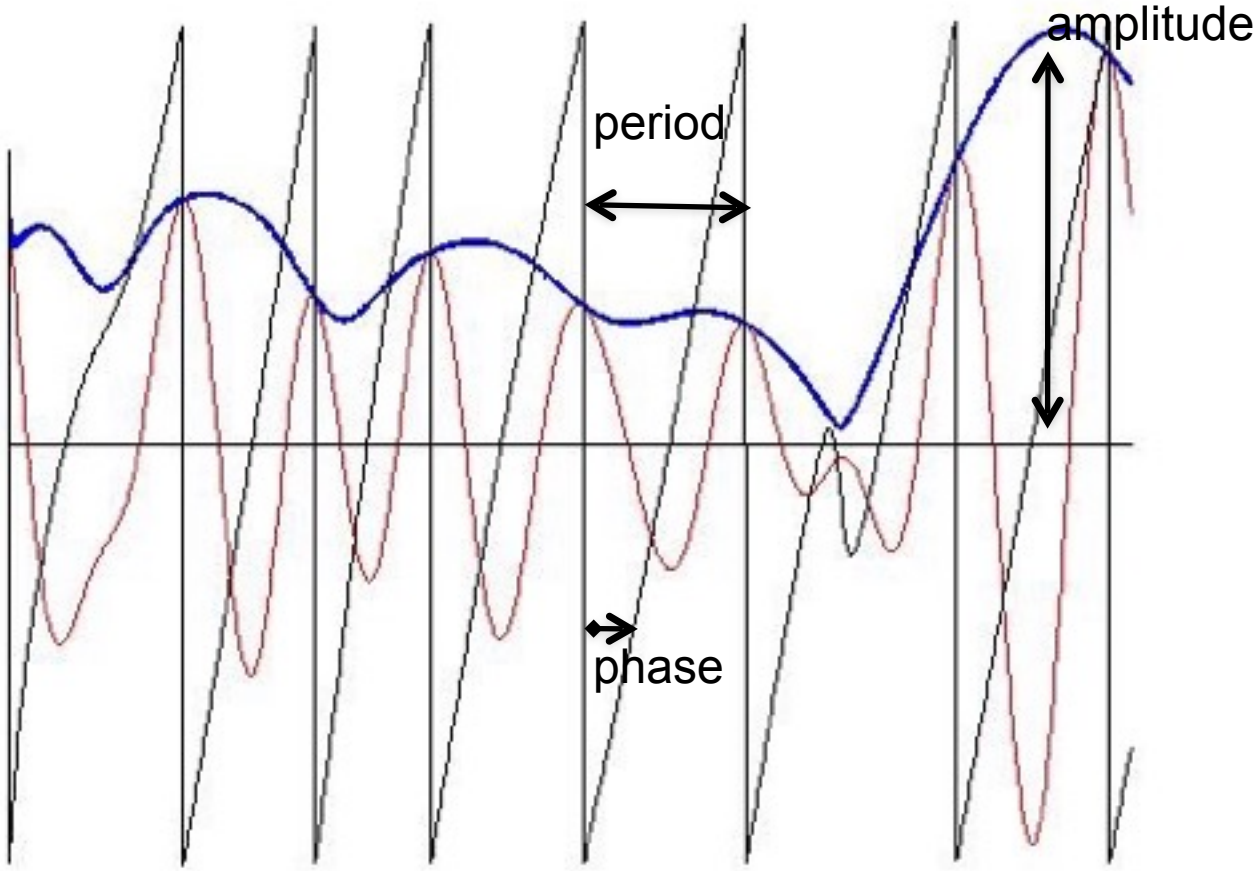
Hoogenboom et al, 2006



Outline

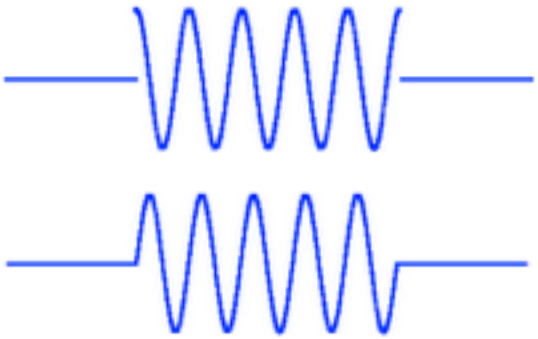
- Spectral analysis: going from time to frequency domain
- Issues with finite and discrete sampling
- Spectral leakage and (multi-)tapering
- Time-frequency analysis

A background note on oscillations

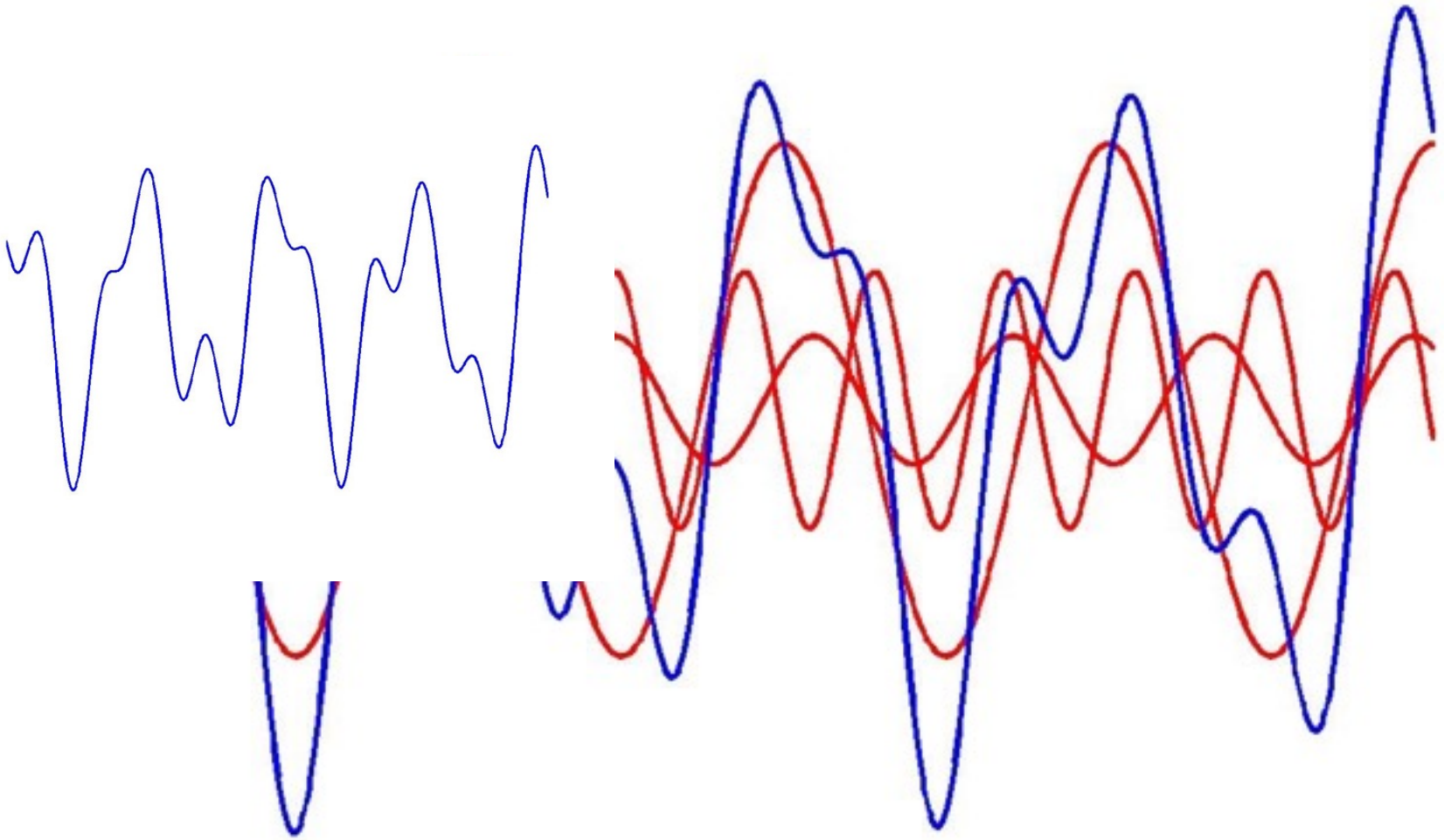


Spectral analysis

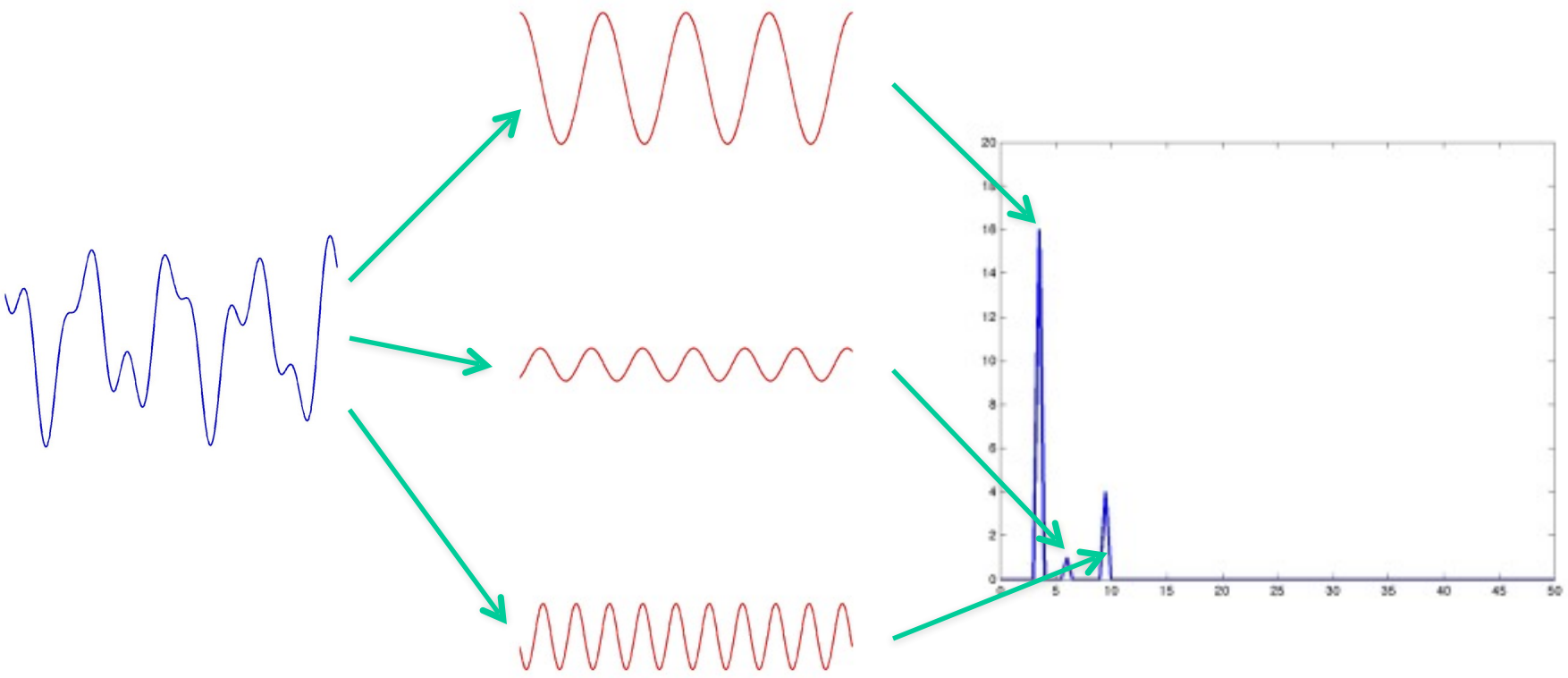
- Deconstructing a time domain signal into its constituent oscillatory components, a.k.a. Fourier analysis
- Using simple oscillatory functions: cosines and sines



Spectral decomposition: the principle



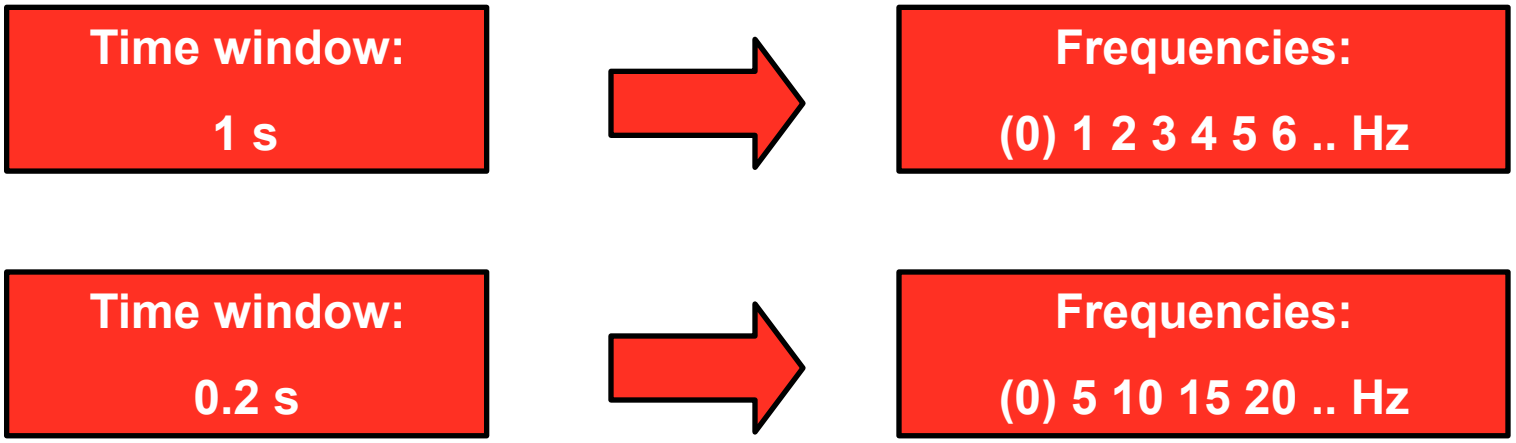
Spectral decomposition: the power spectrum



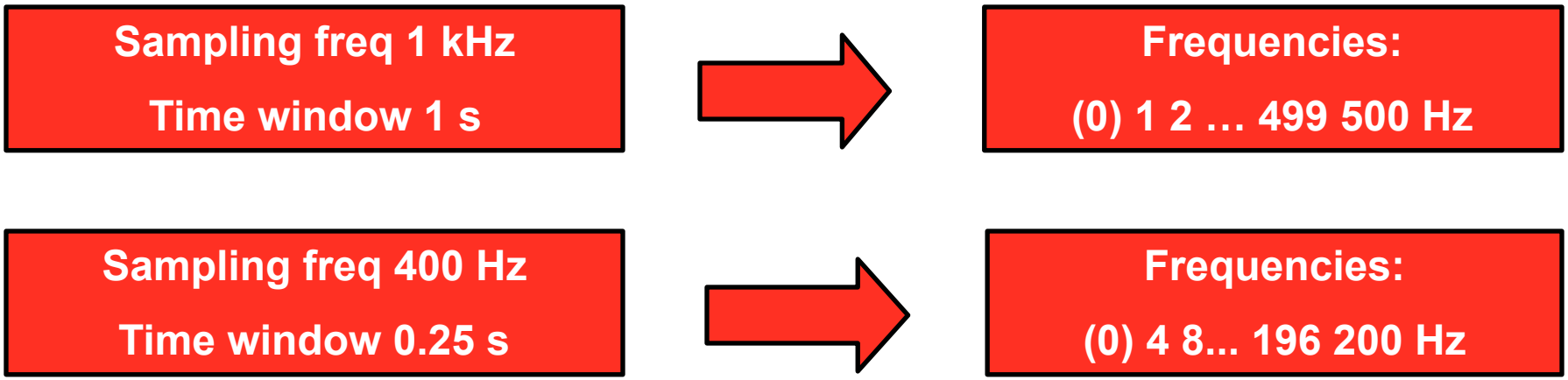
Spectral analysis

- Deconstructing a time domain signal into its constituent oscillatory components, a.k.a. Fourier analysis
- Using simple oscillatory functions: cosines and sines
- Express signal as function of frequency, rather than time
- Concept: linear regression using oscillatory basis functions

Time-frequency relation



Time-frequency relation

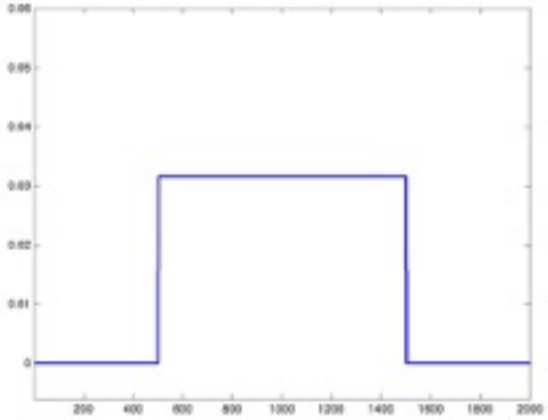


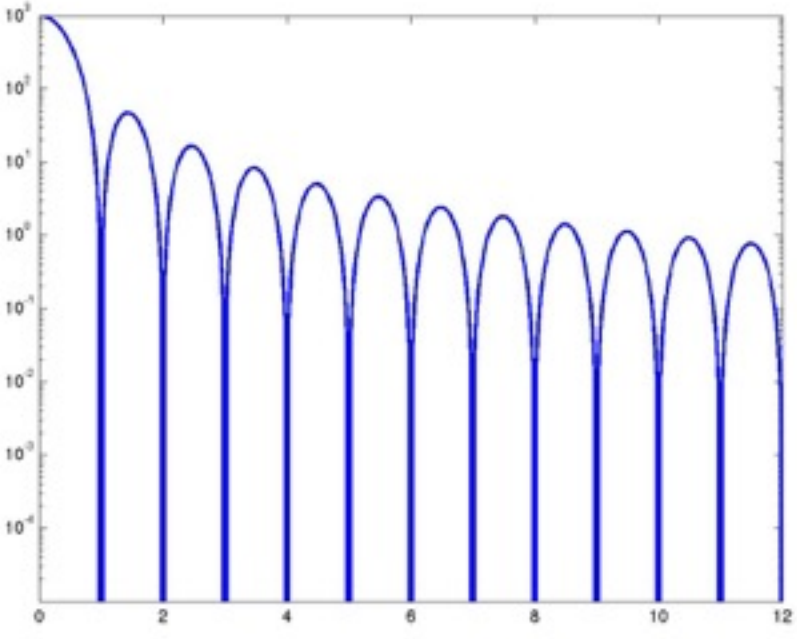
Spectral analysis

- Deconstructing a time domain signal into its constituent oscillatory components, a.k.a. Fourier analysis
- Using simple oscillatory functions: cosines and sines
- Express signal as function of frequency, rather than time
- Concept: linear regression using oscillatory basis functions
- Each oscillatory component has an amplitude and phase
- Discrete and finite sampling constrains the frequency axis

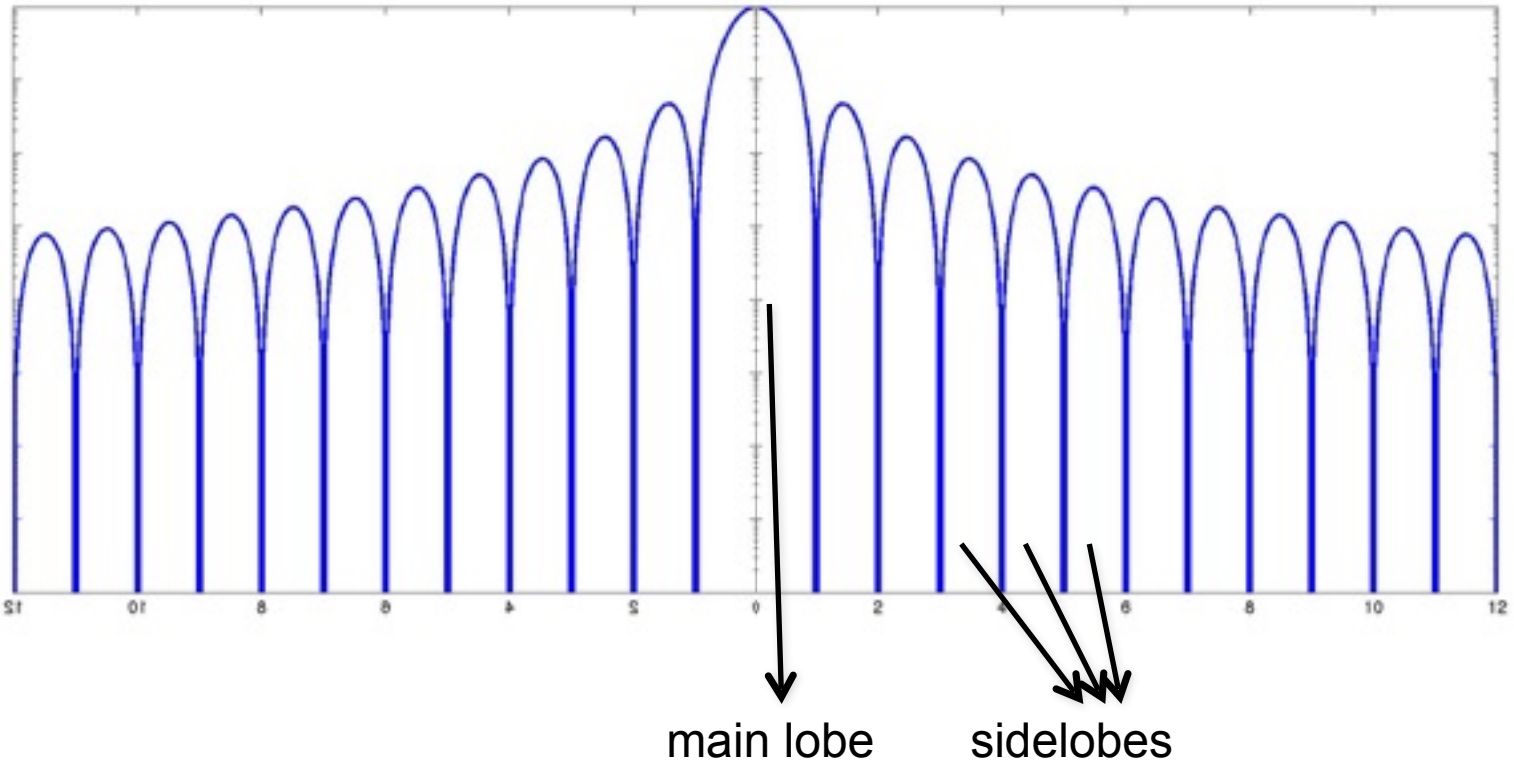
Goal and challenges

Spectral leakage and tapering

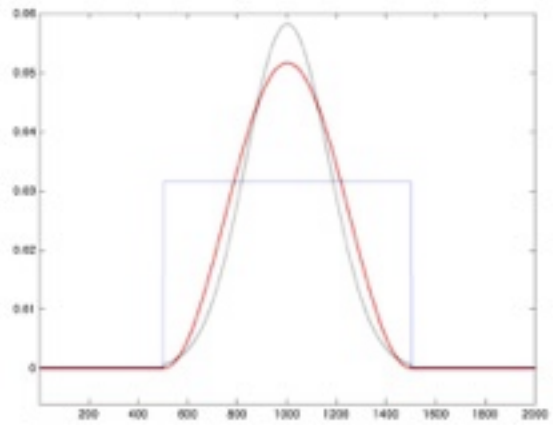


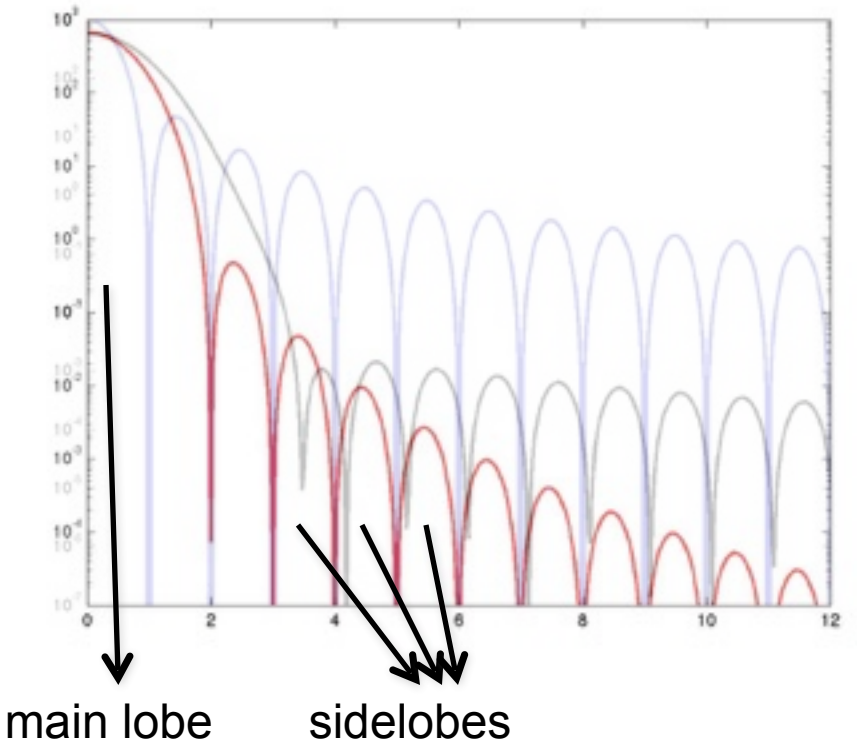


Spectral leakage



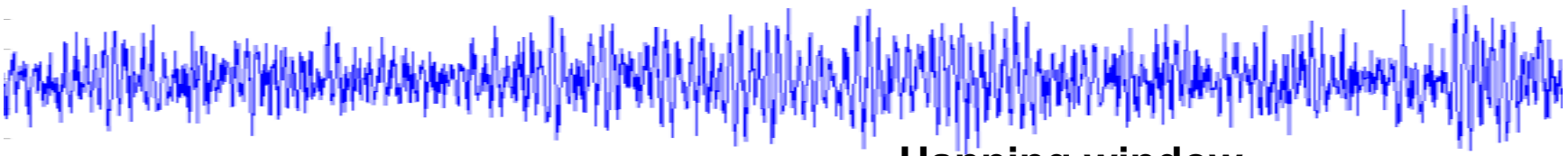
Spectral leakage and tapering





Multitapers

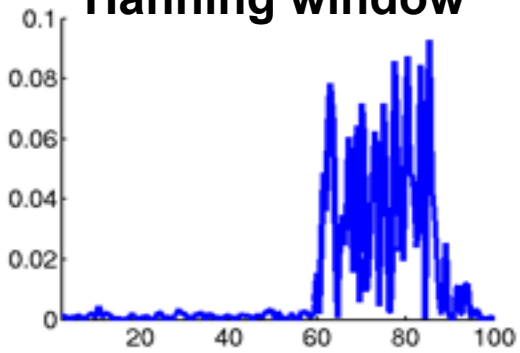
Multitapered spectral analysis



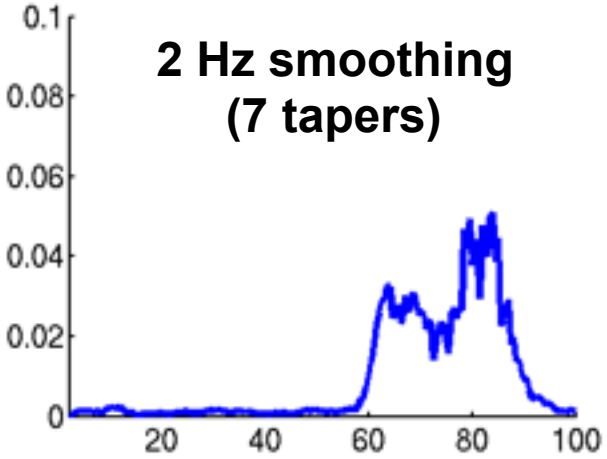
2 s

broadband activity between 60-90 Hz

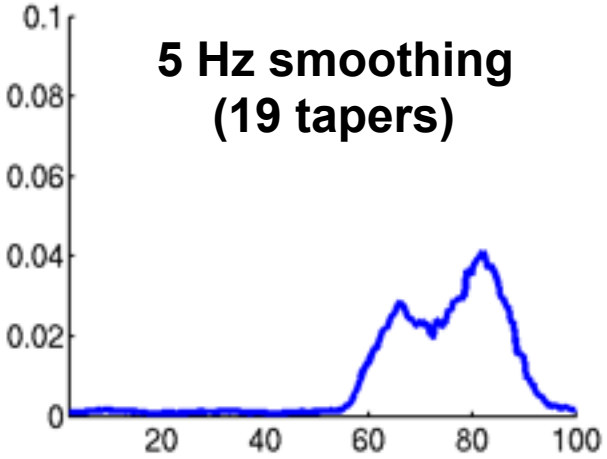
Hanning window



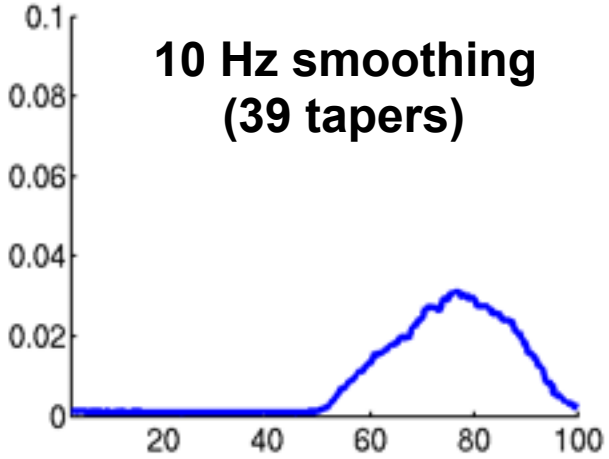
2 Hz smoothing (7 tapers)



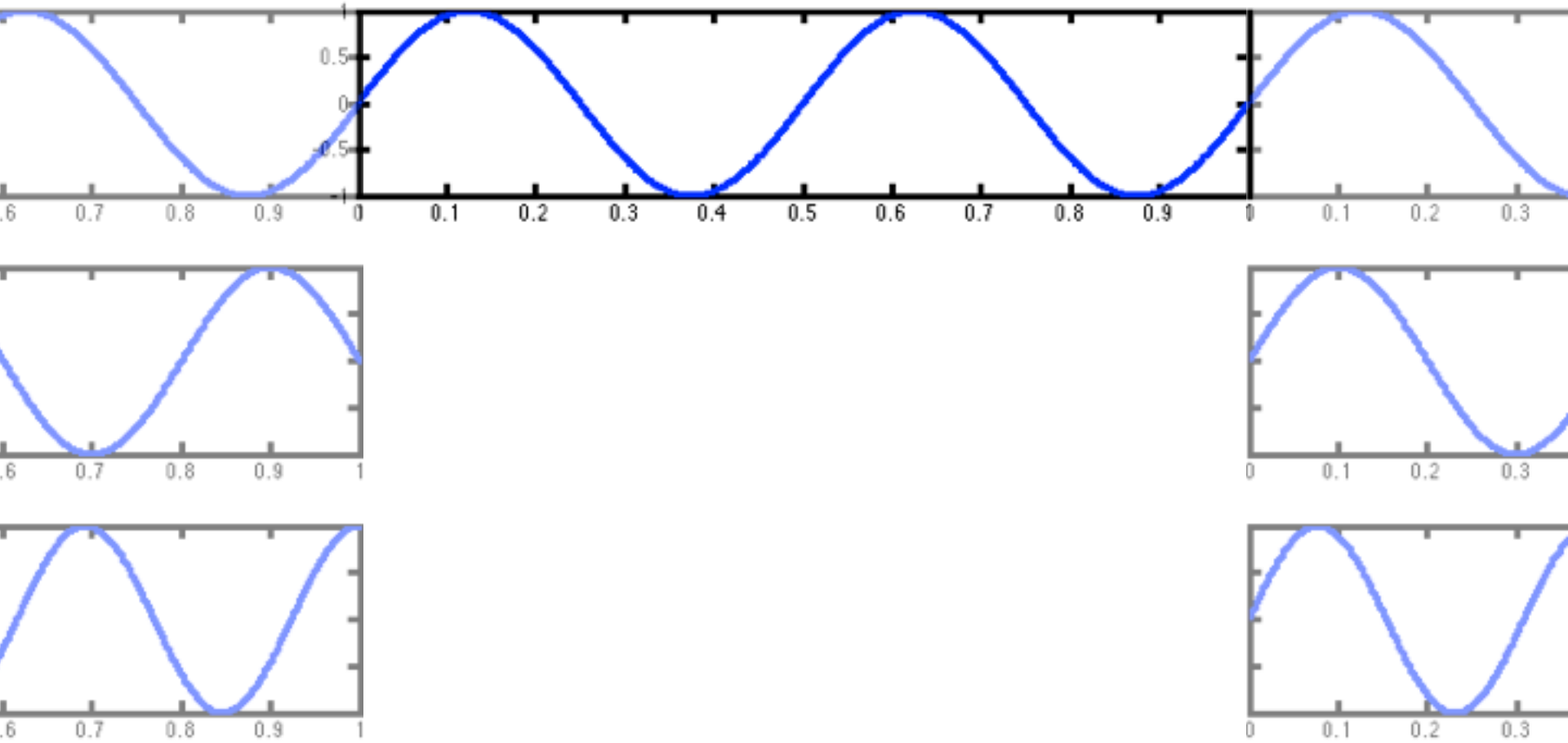
5 Hz smoothing (19 tapers)



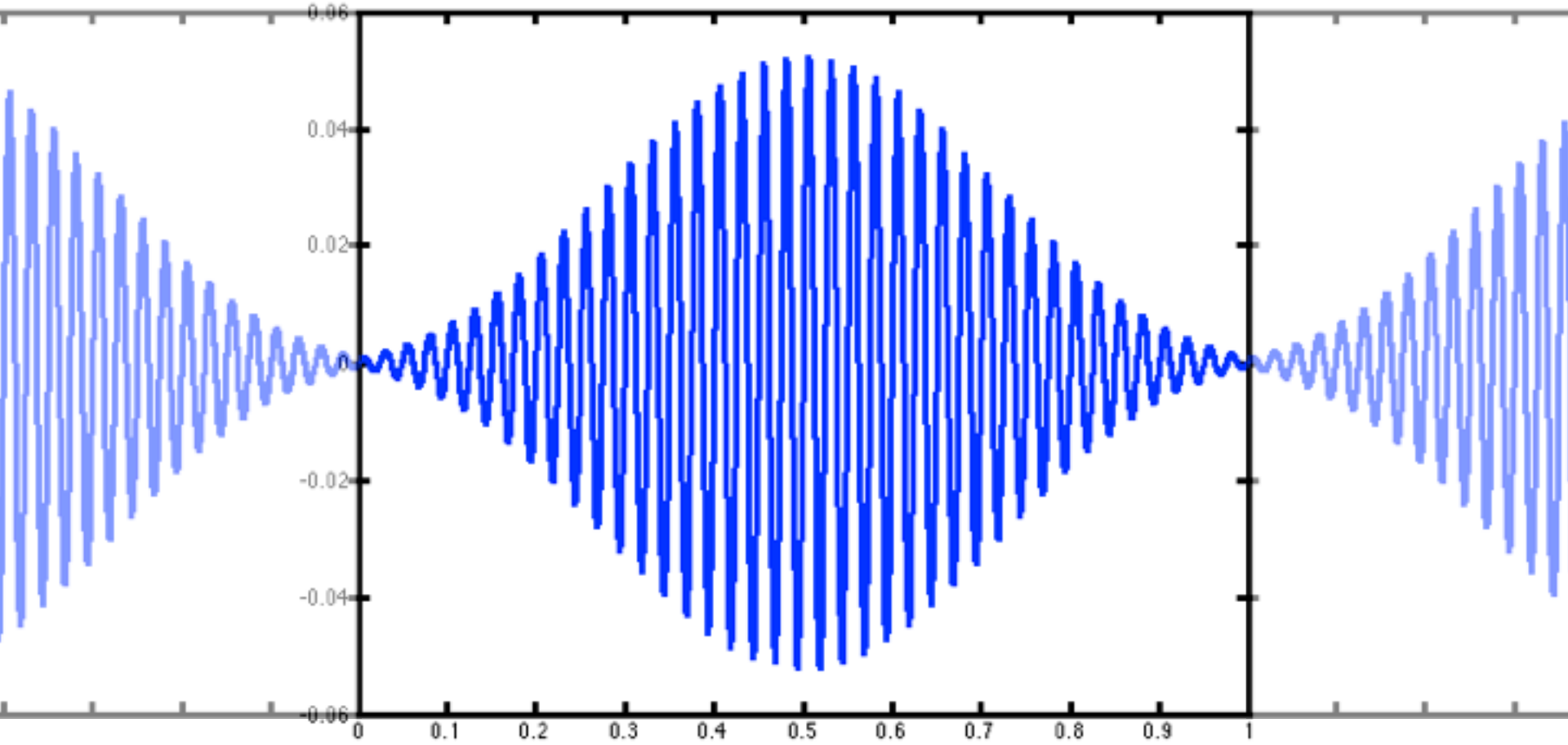
10 Hz smoothing (39 tapers)



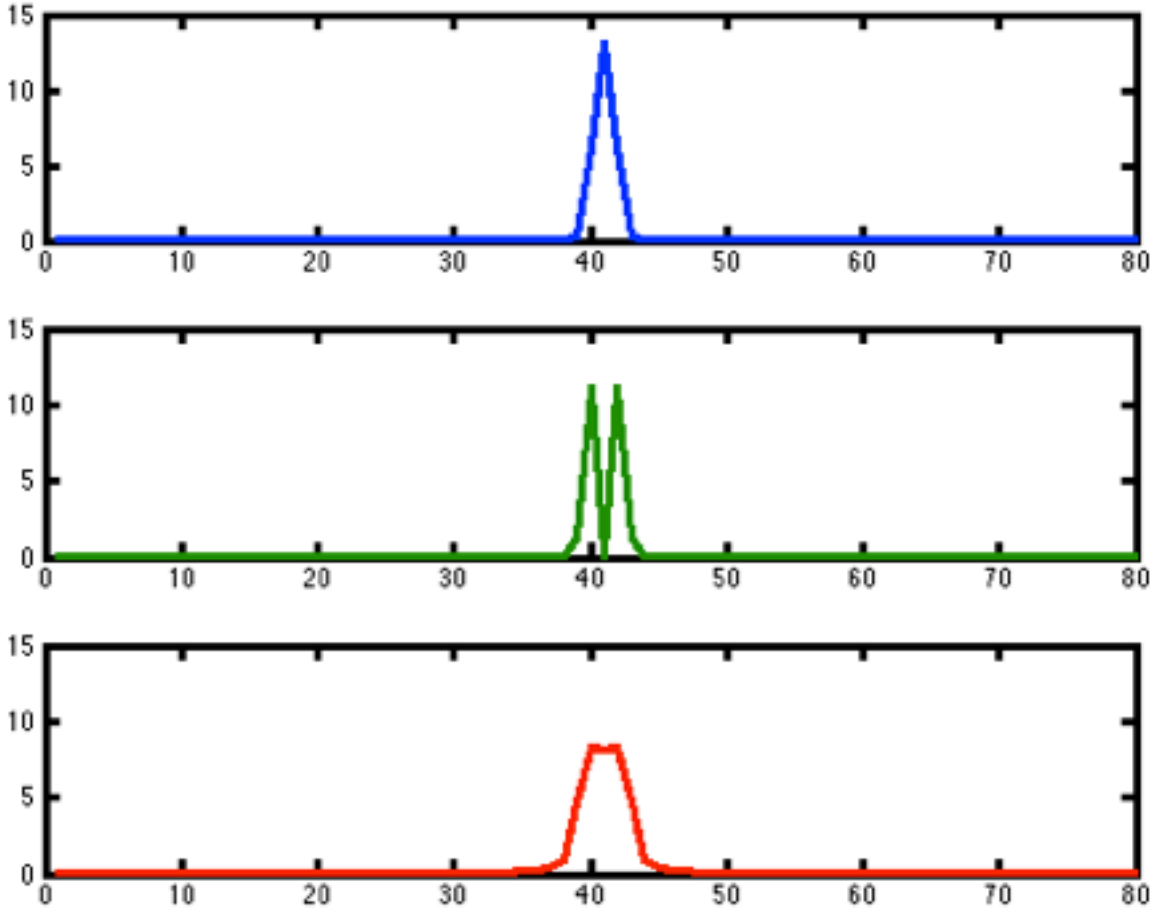
Tapering in spectral analysis



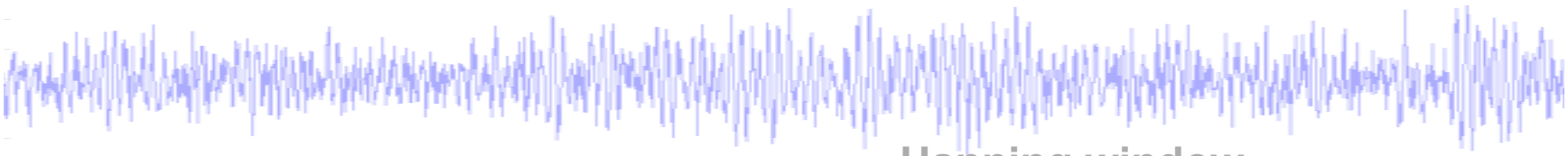
Tapering in spectral analysis



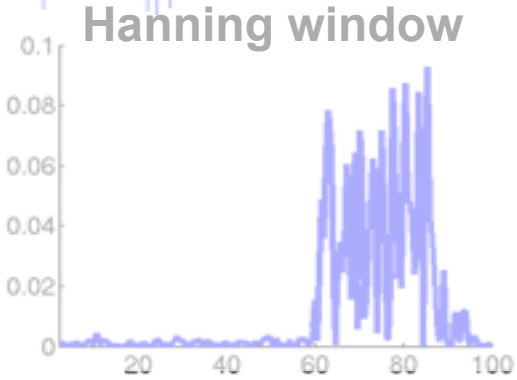
Multitapered spectral analysis

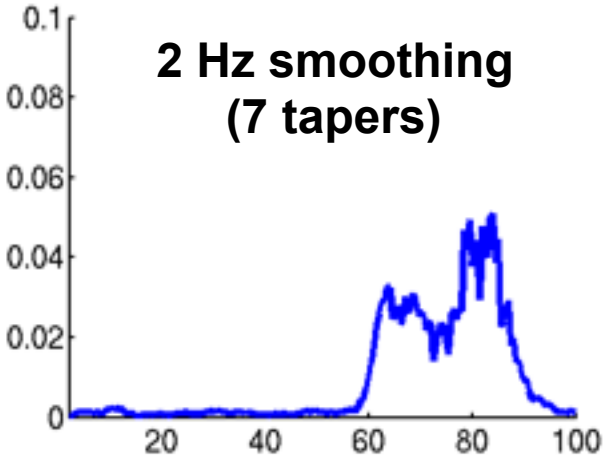


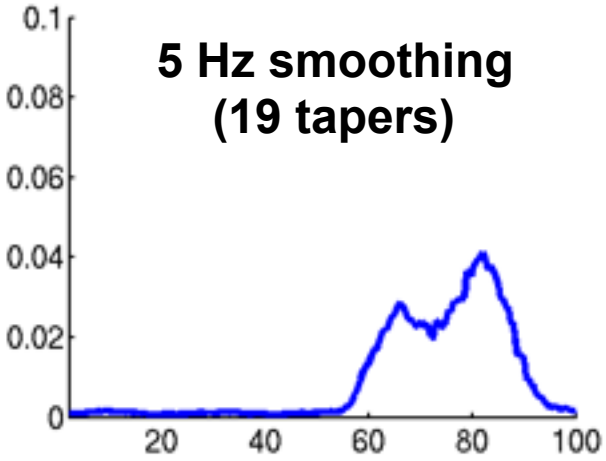
Multitapered spectral analysis

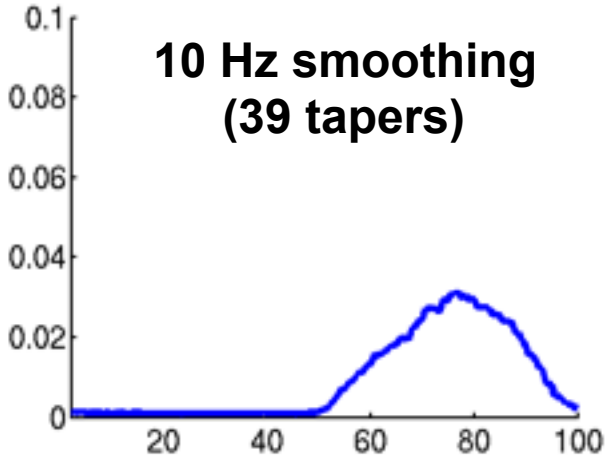


broadband activity
between 60-90 Hz





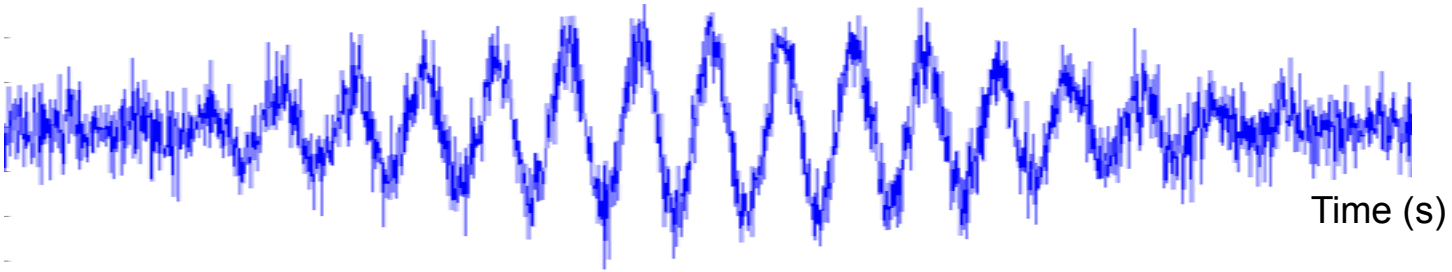




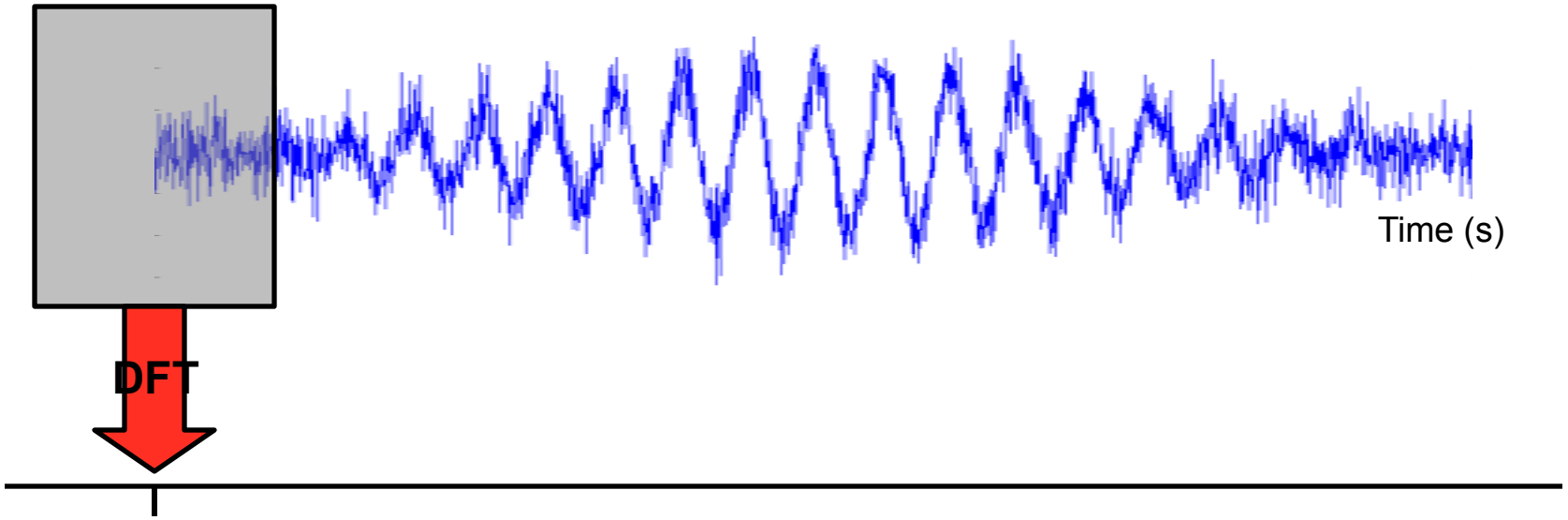
Sub summary

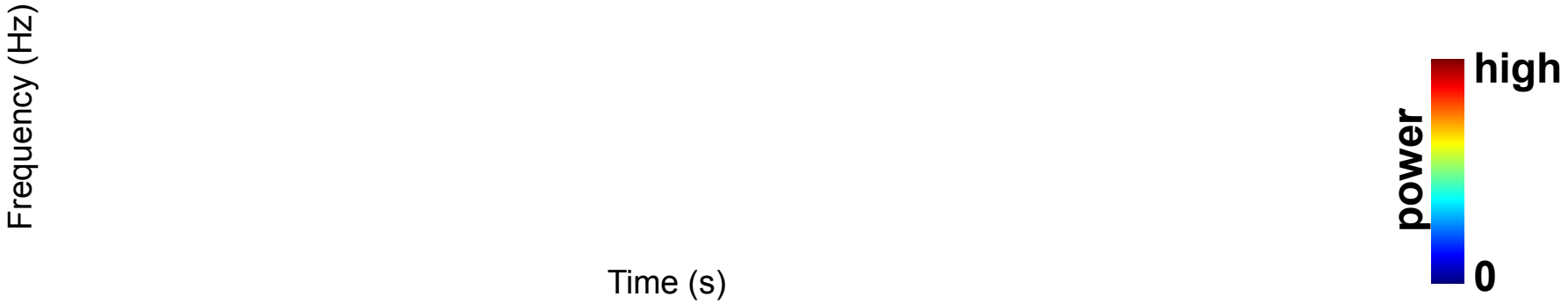
- Spectral analysis
  - Decompose signal into its constituent oscillatory components
  - Focused on 'stationary' power
- Tapers
  - Boxcar, Hanning, Gaussian
- Multitapers
  - Control spectral leakage/smoothing

Time frequency analysis

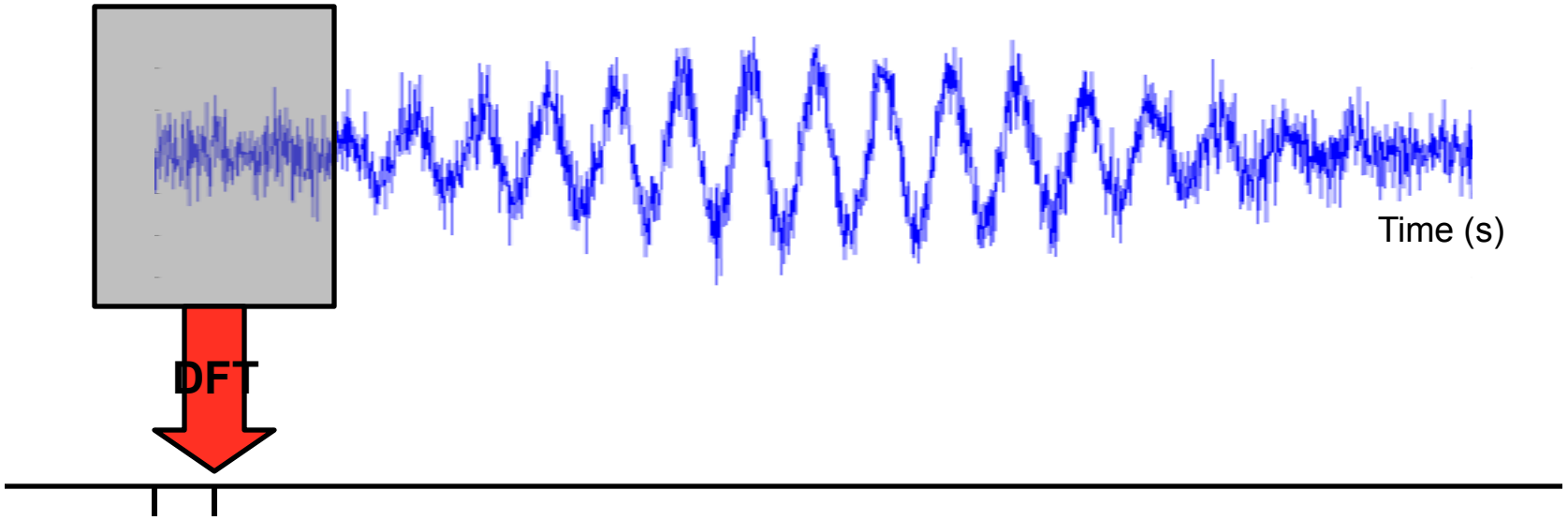


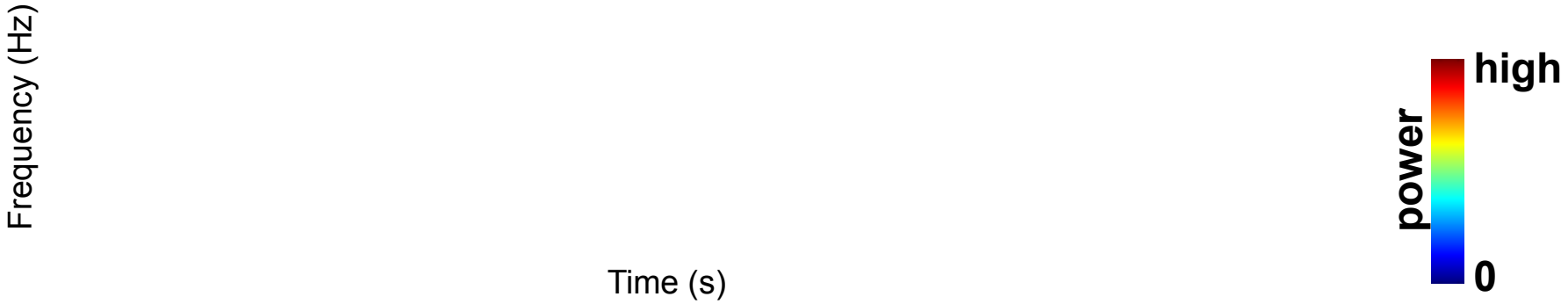
Time frequency analysis





Time frequency analysis





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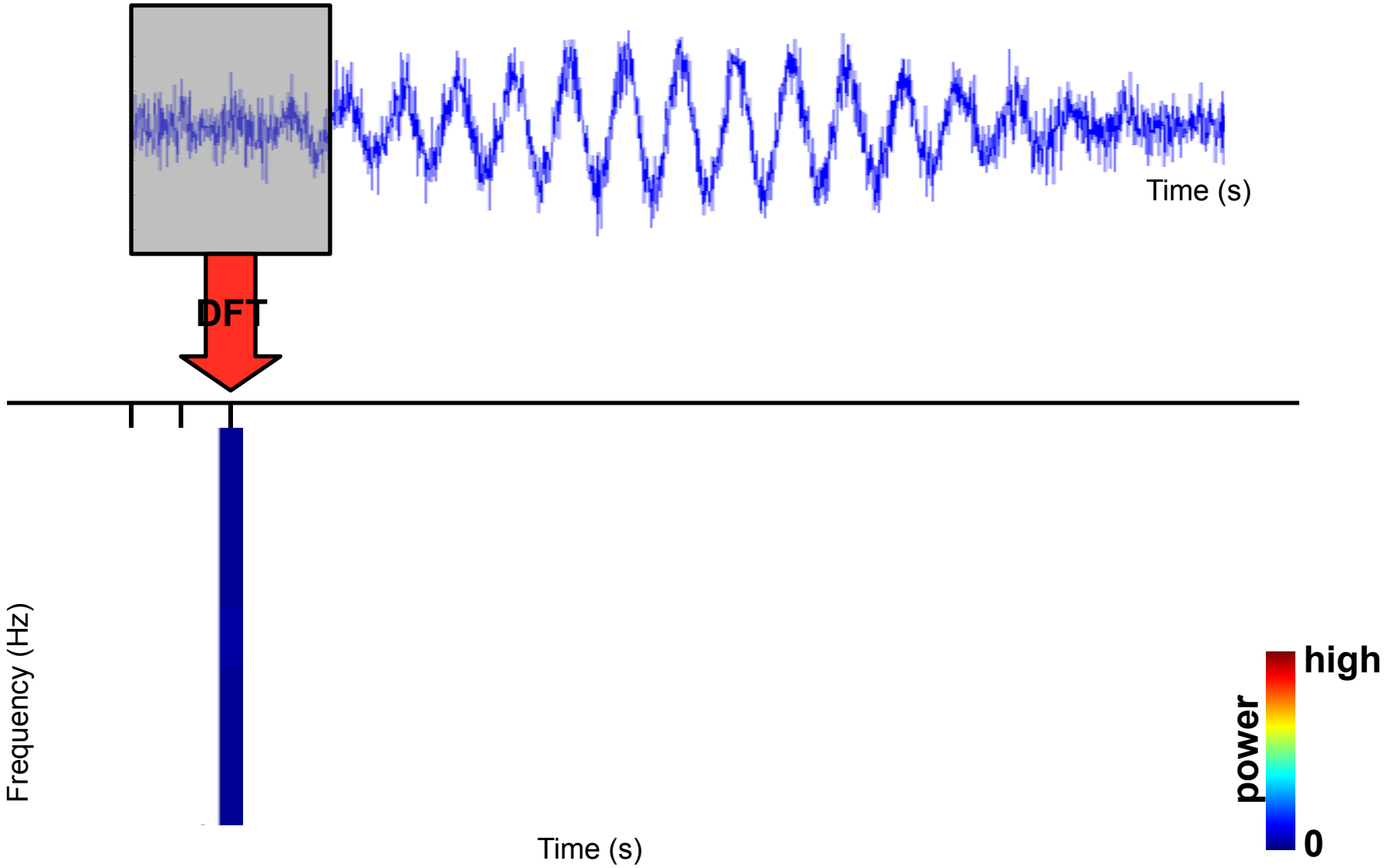
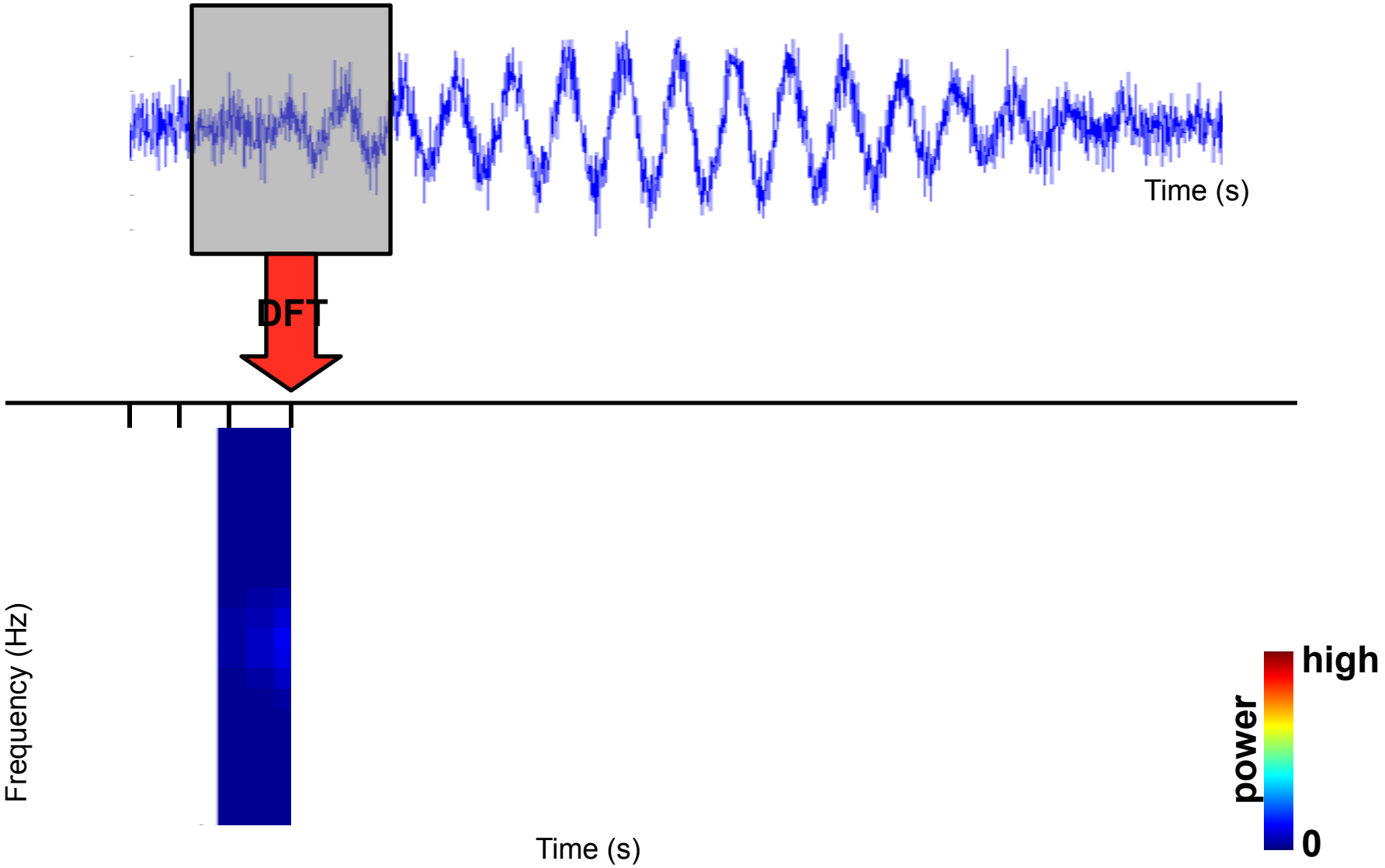
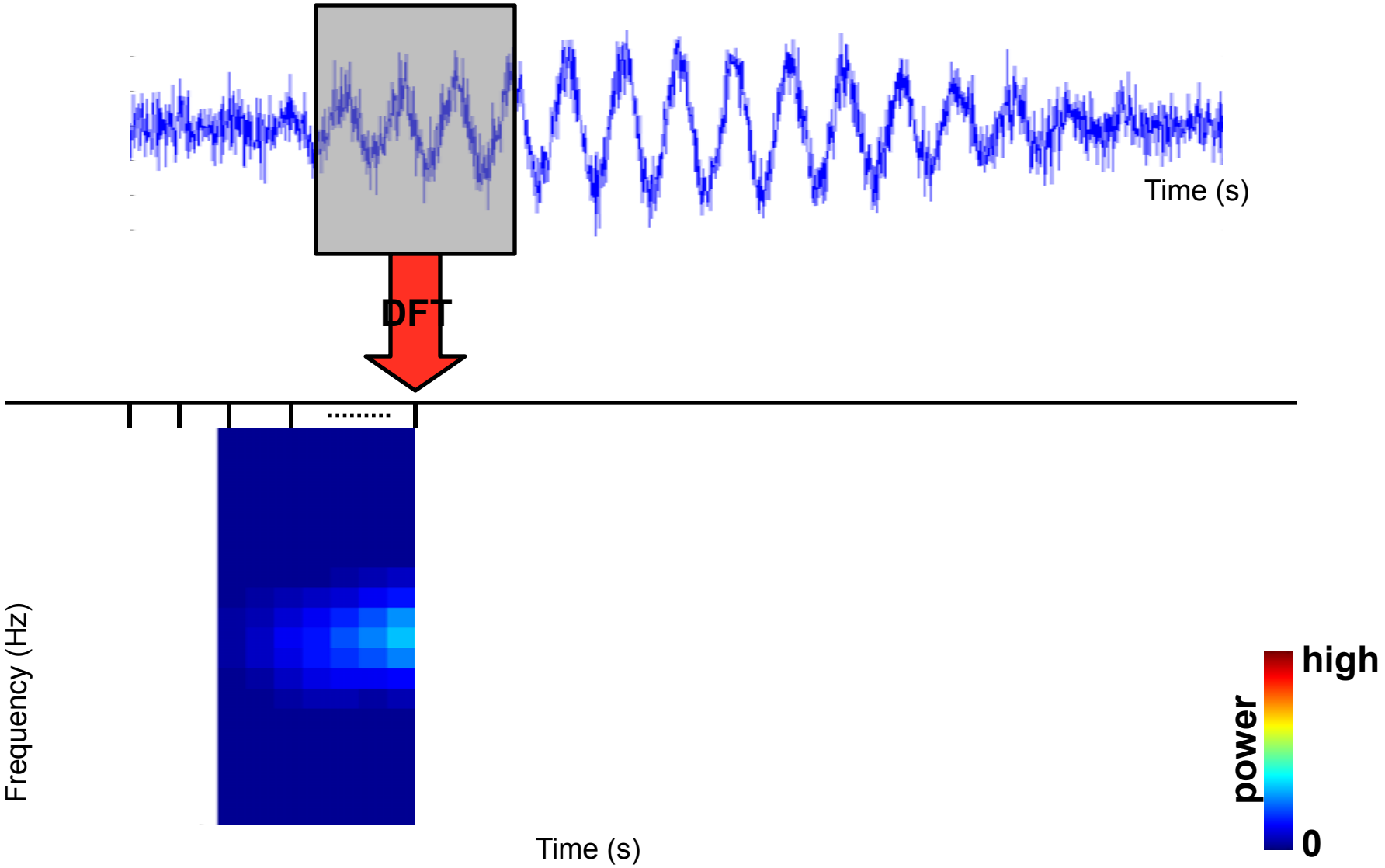


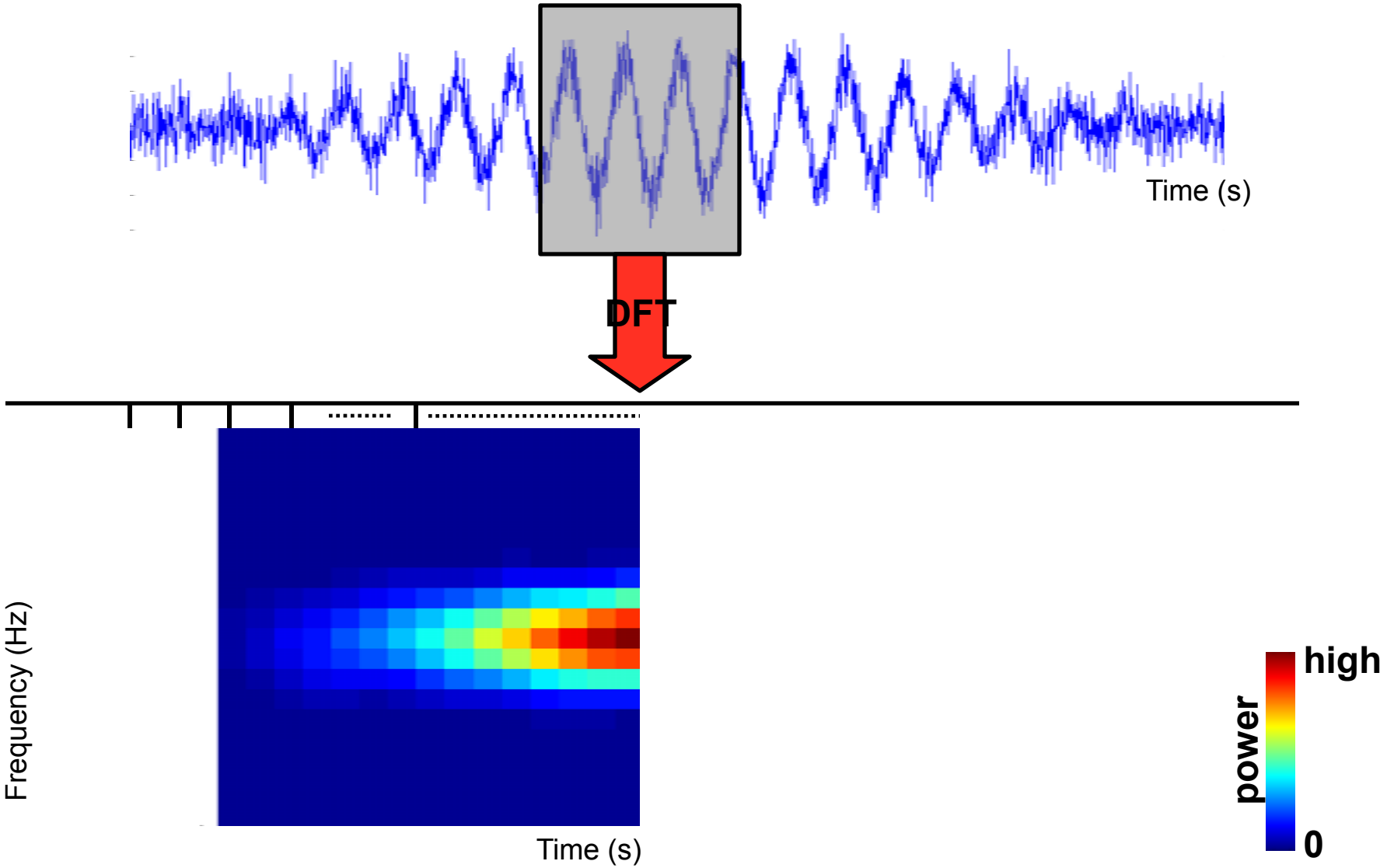
Time frequency analysis



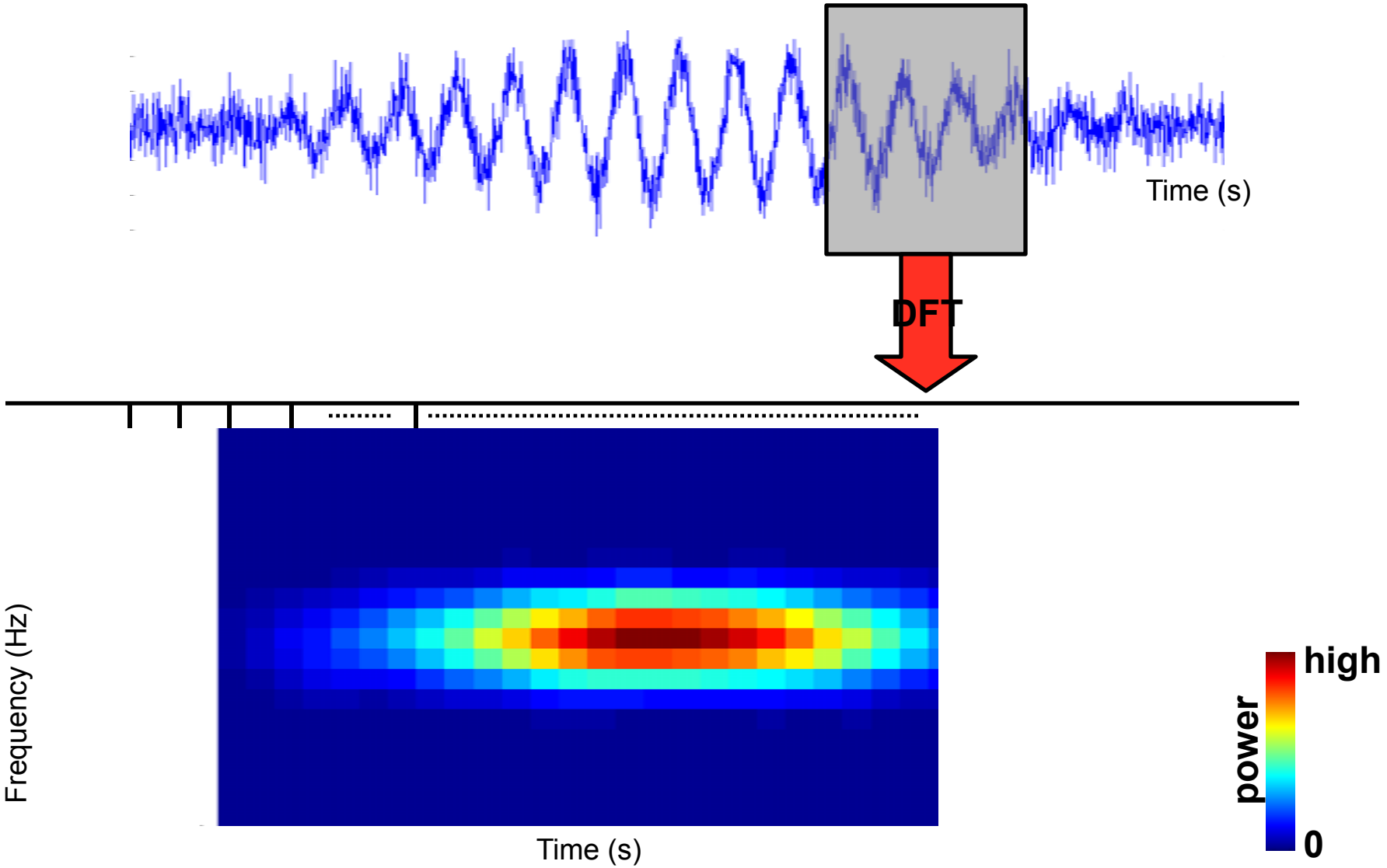
Time frequency analysis



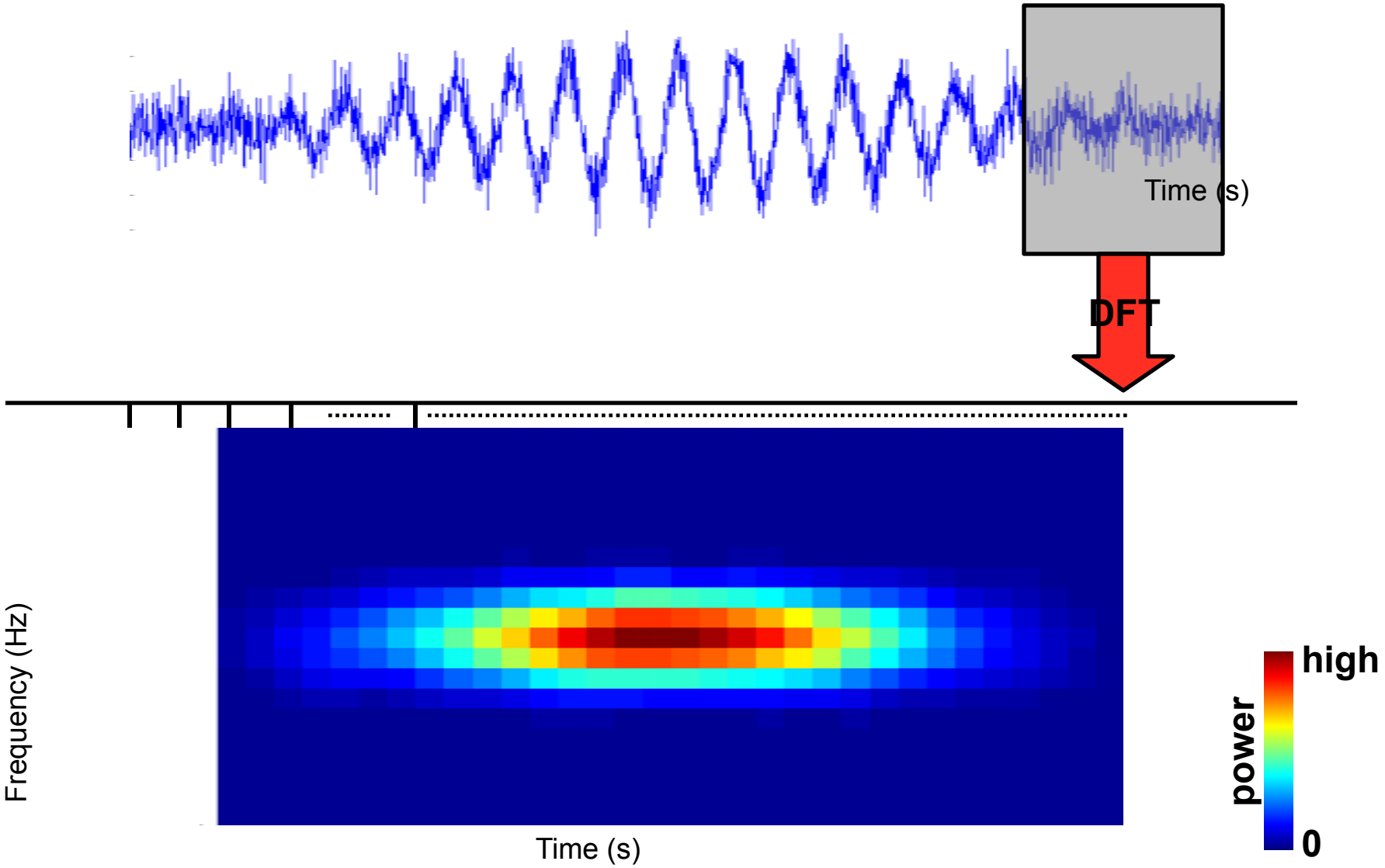
Time frequency analysis



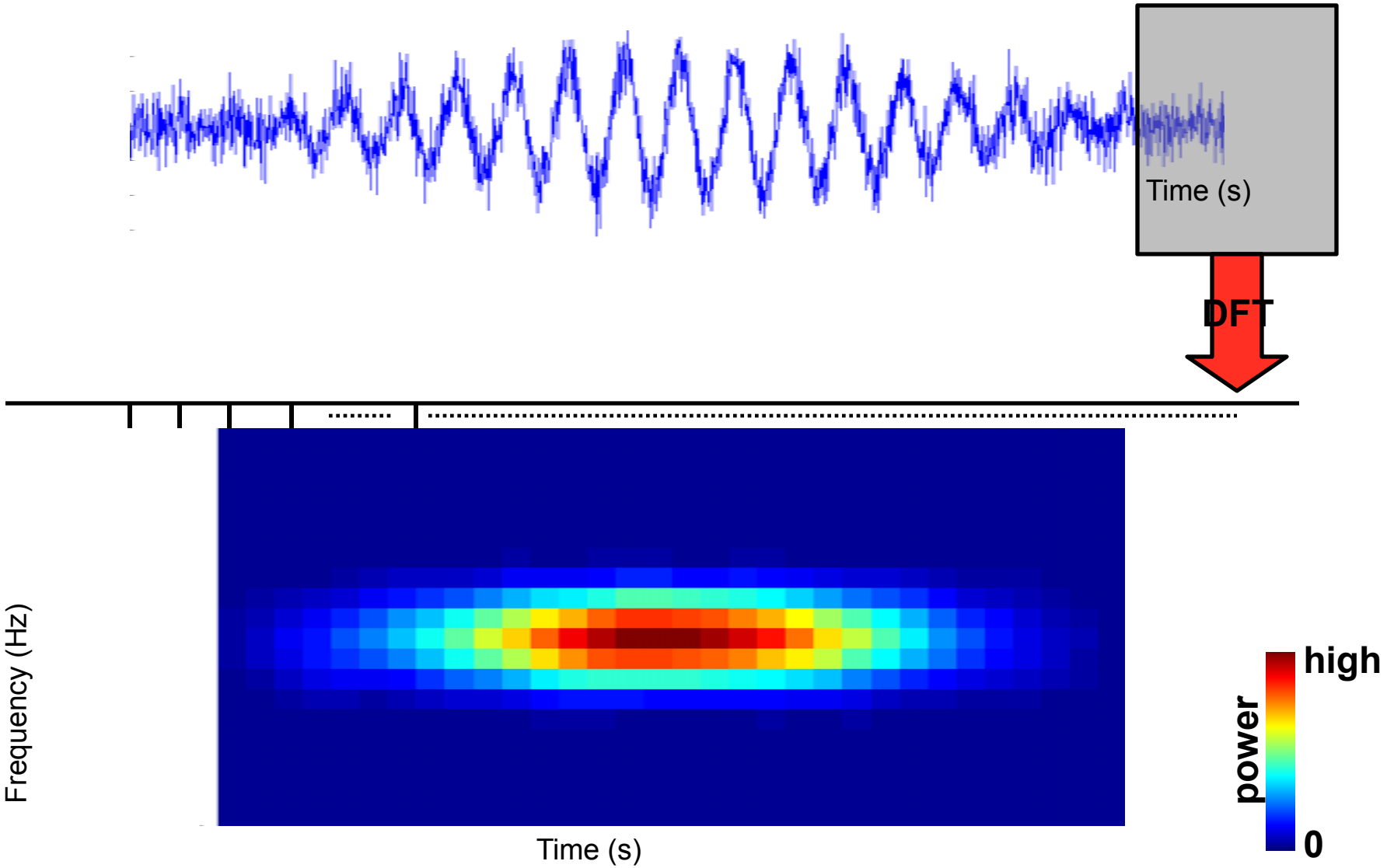
Time frequency analysis



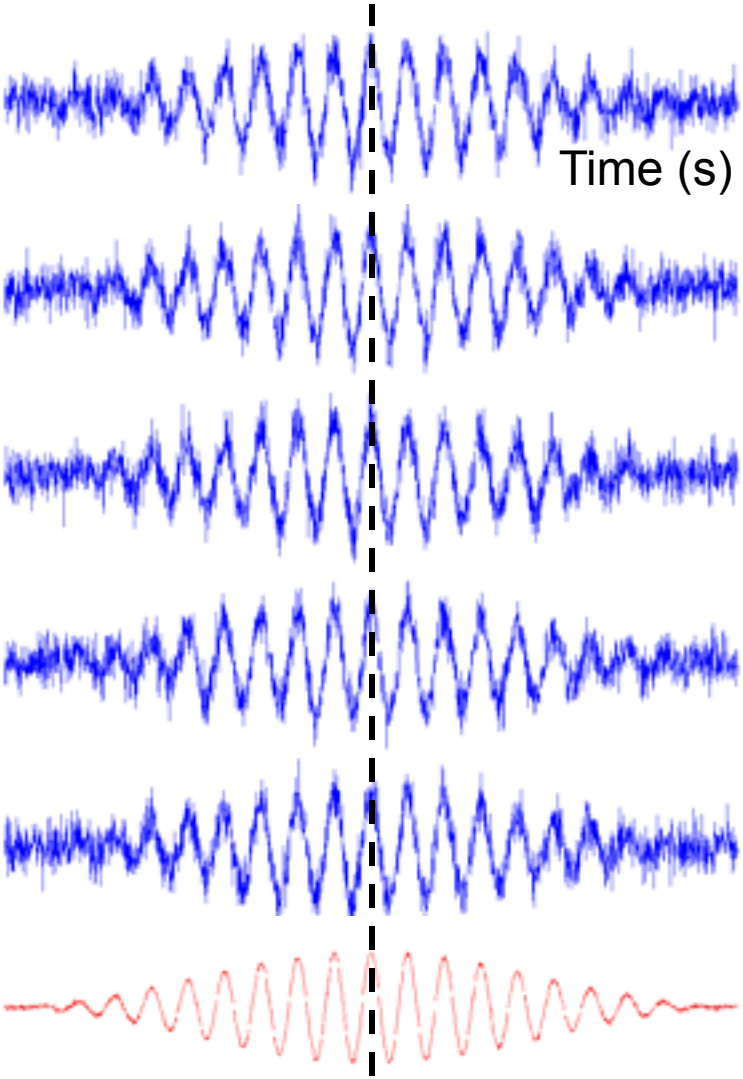
Time frequency analysis

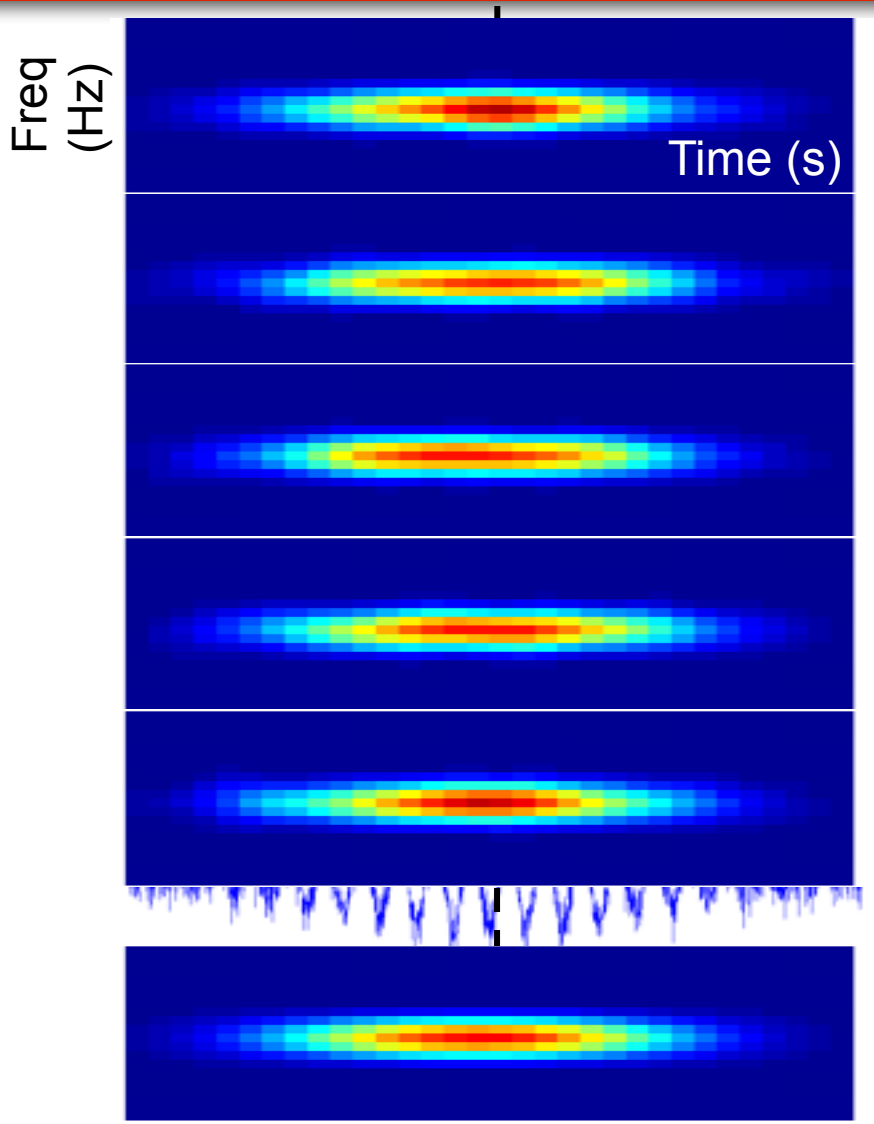


Time frequency analysis

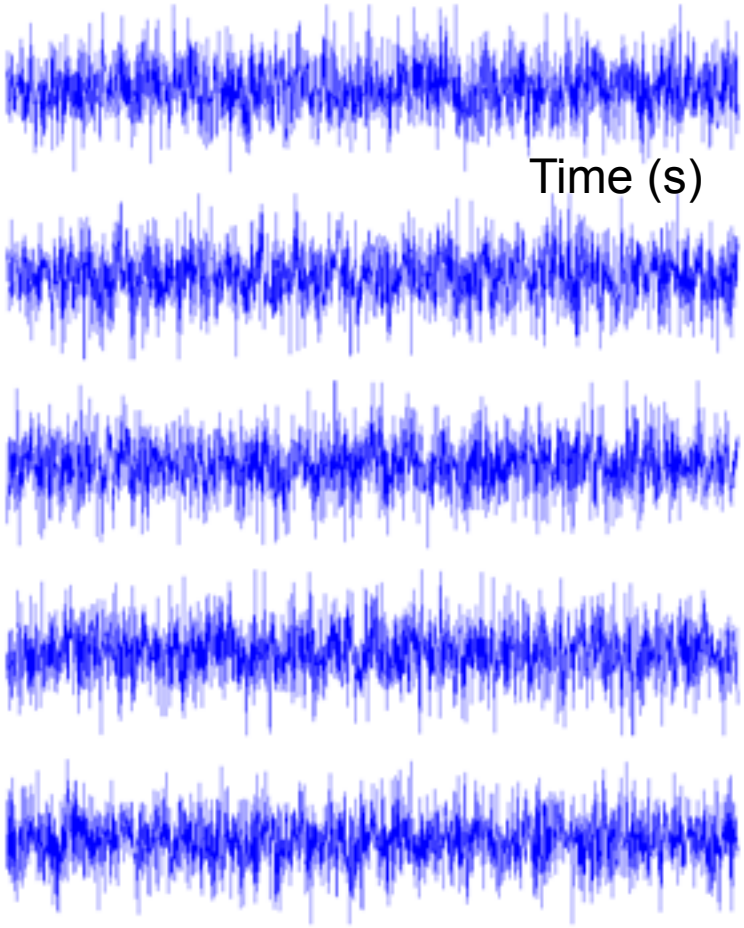


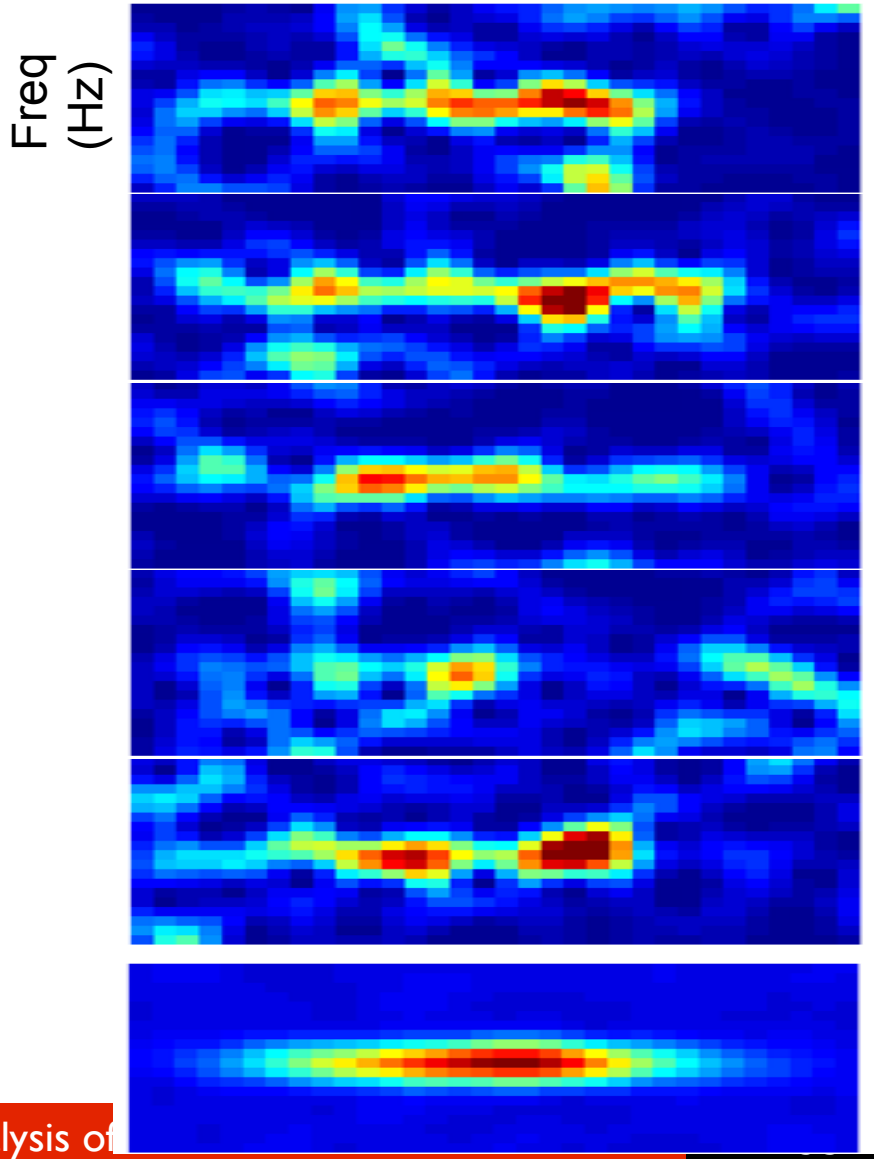
Evoked vs. induced activity



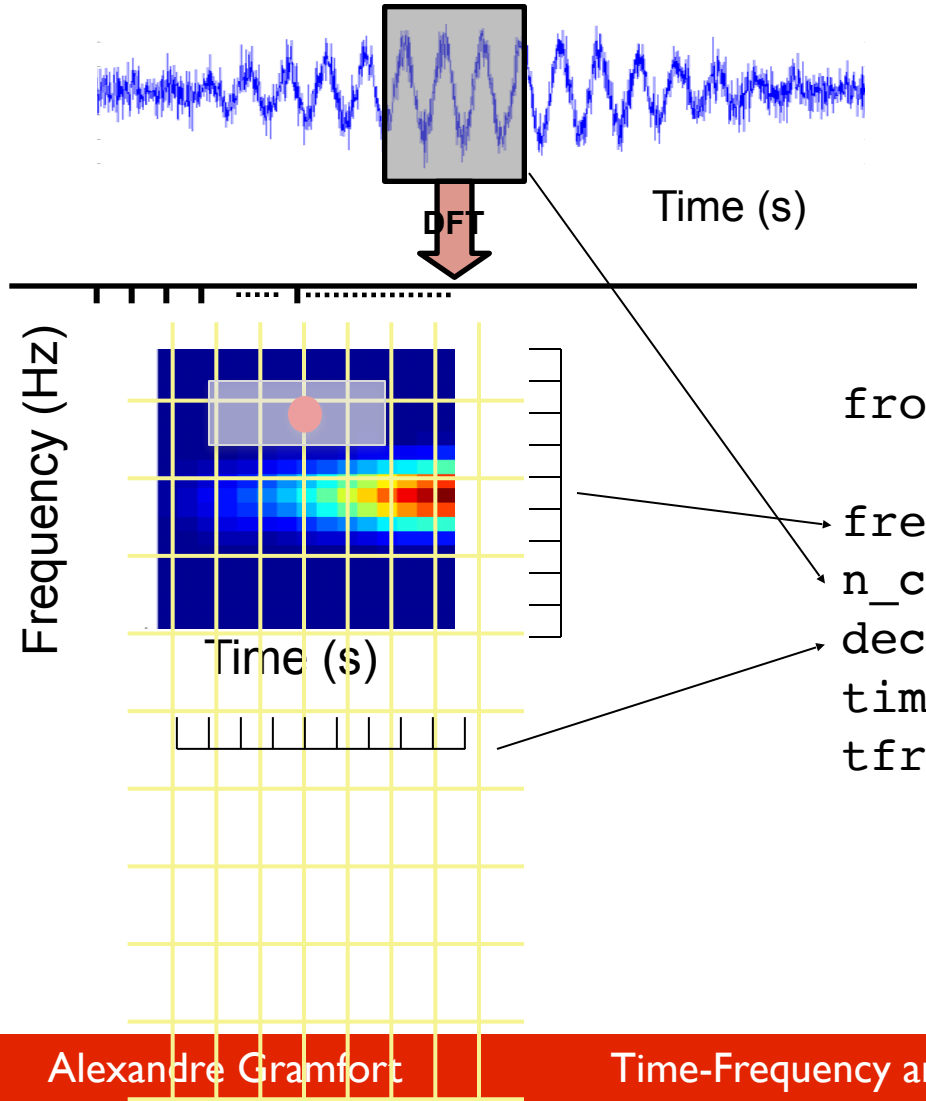


Noisy signal ⇒ many trials needed



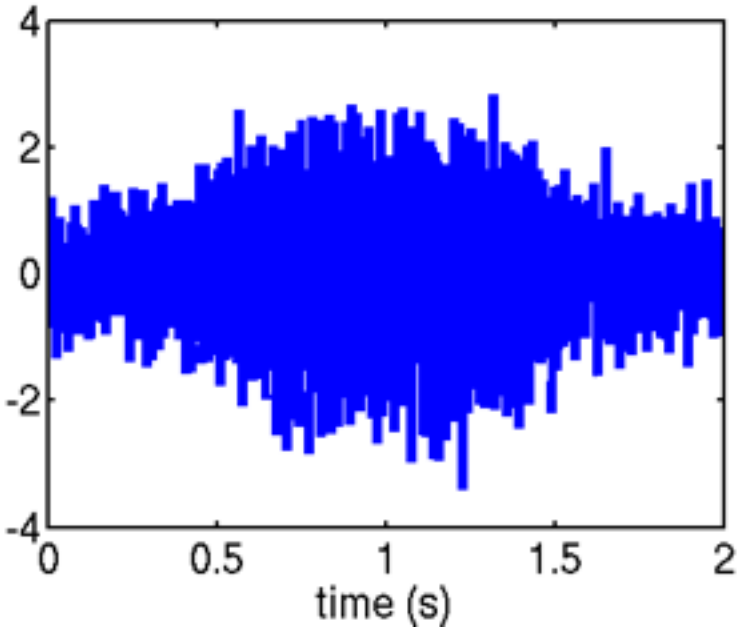


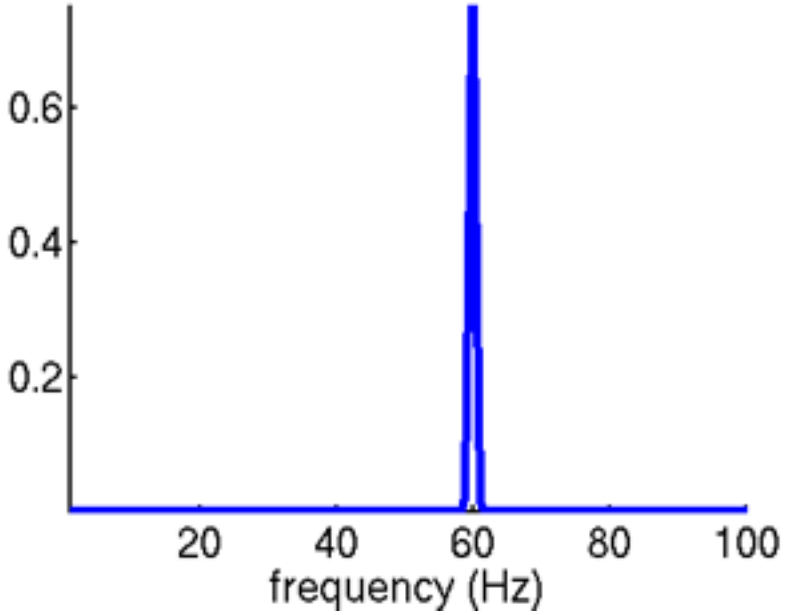
The time-frequency plane




```
from mne.time_frequency \
    import tfr_mutlitaper
freqs = np.arange(2, 41, 2)
n_cycles = freqs / 2
decim = 2  # save memory
time_bandwidth = 4.  # smoothing
tfr = tfr_multitaper(inst,
    freqs=freqs,
    n_cycles=n_cycles,
    time_bandwidth=time_bandwidth)
```

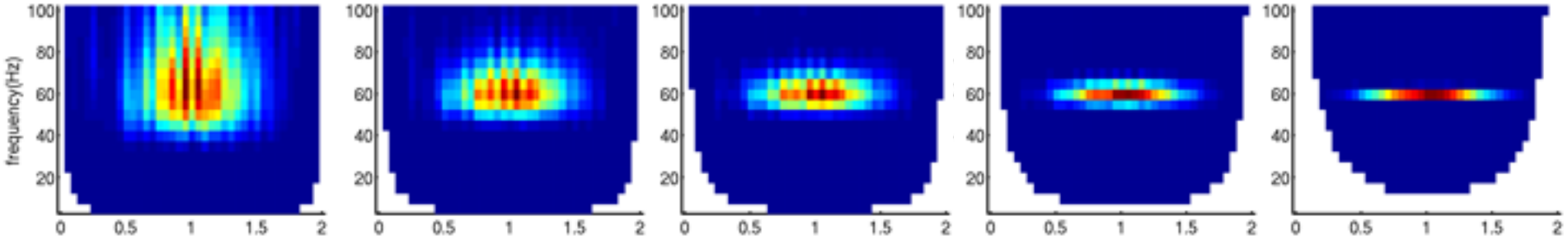
Time versus frequency resolution





short timewindow

long timewindow



Sub summary

- Time frequency analysis
  - Fourier analysis on shorter sliding time window
- Evoked & Induced activity
- Time frequency resolution trade off

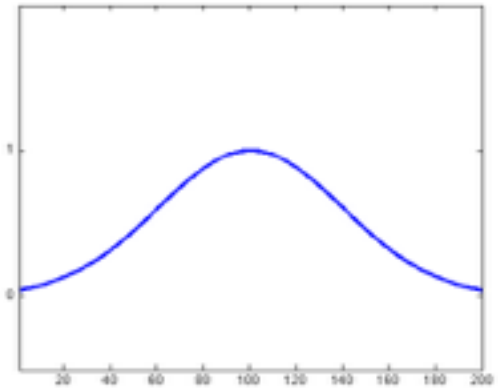
Wavelet analysis

- Popular method to calculate time-frequency representations
- Is based on convolution of signal with a family of 'wavelets' which capture different frequency components in the signal
- Convolution ~ local correlation

see tfr_morlet function

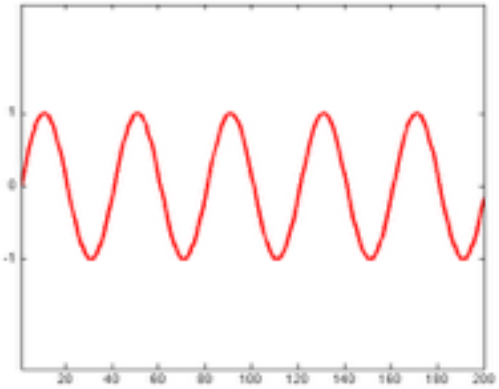
Wavelets

Taper



X

Sine wave



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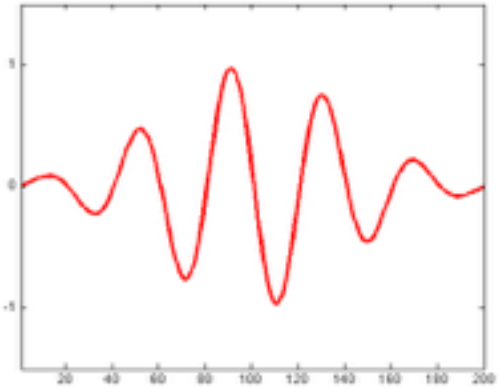
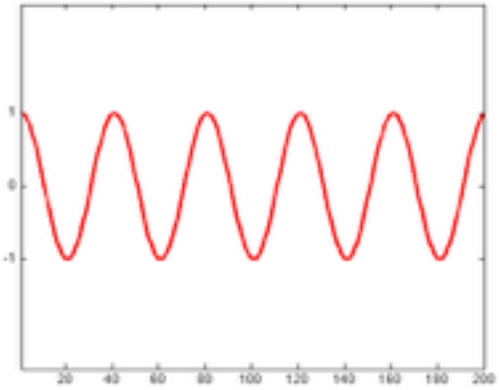


Cosine wave



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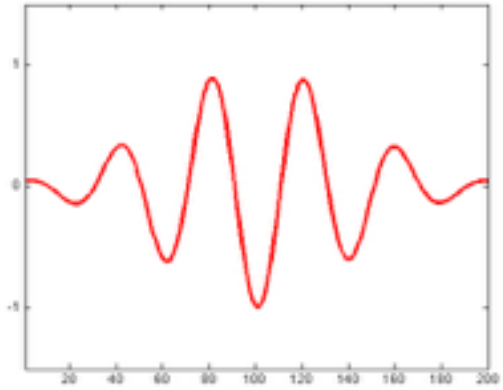
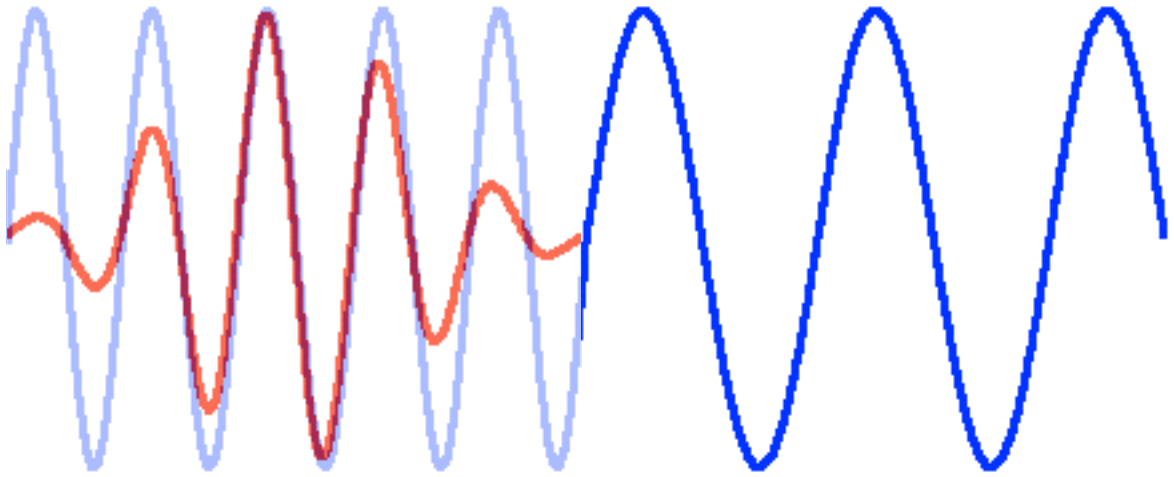
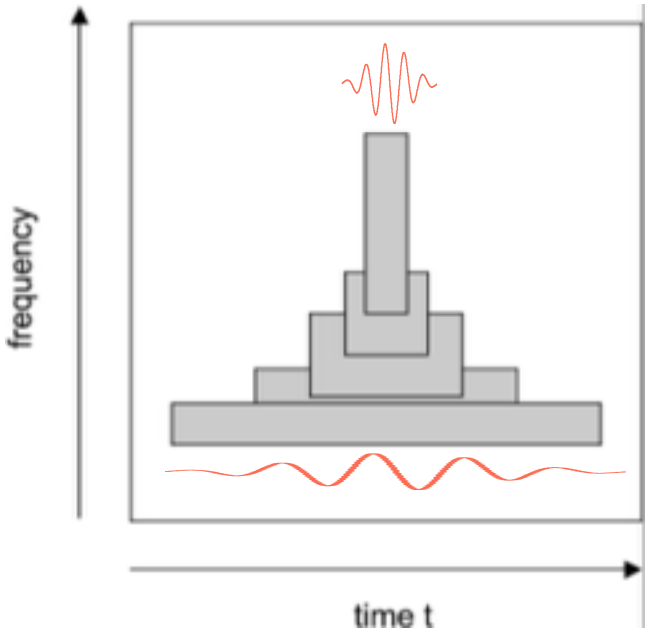


Convolution



Wavelet analysis

- Wavelet width determines time-frequency resolution
- Width function of frequency (often 5 cycles)
- ‘Long’ wavelet at low frequencies leads to relatively narrow frequency resolution but poor temporal resolution
- ‘Short’ wavelet at high frequencies leads to broad frequency resolution but more accurate temporal resolution



Summary

- Spectral analysis
  - Relation between time and frequency domains
  - Tapers
- Time frequency analysis
  - Time vs frequency resolution
- Wavelets
- now hands on !