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# Fundamentals of neuronal oscillations and synchrony

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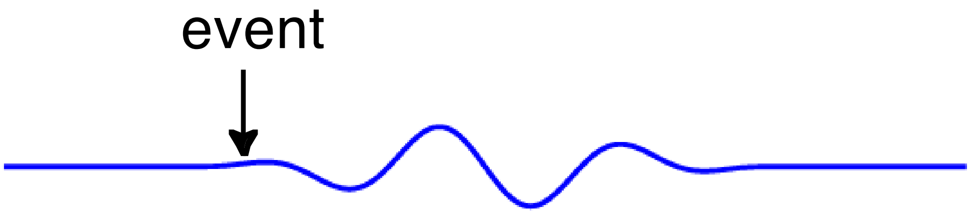
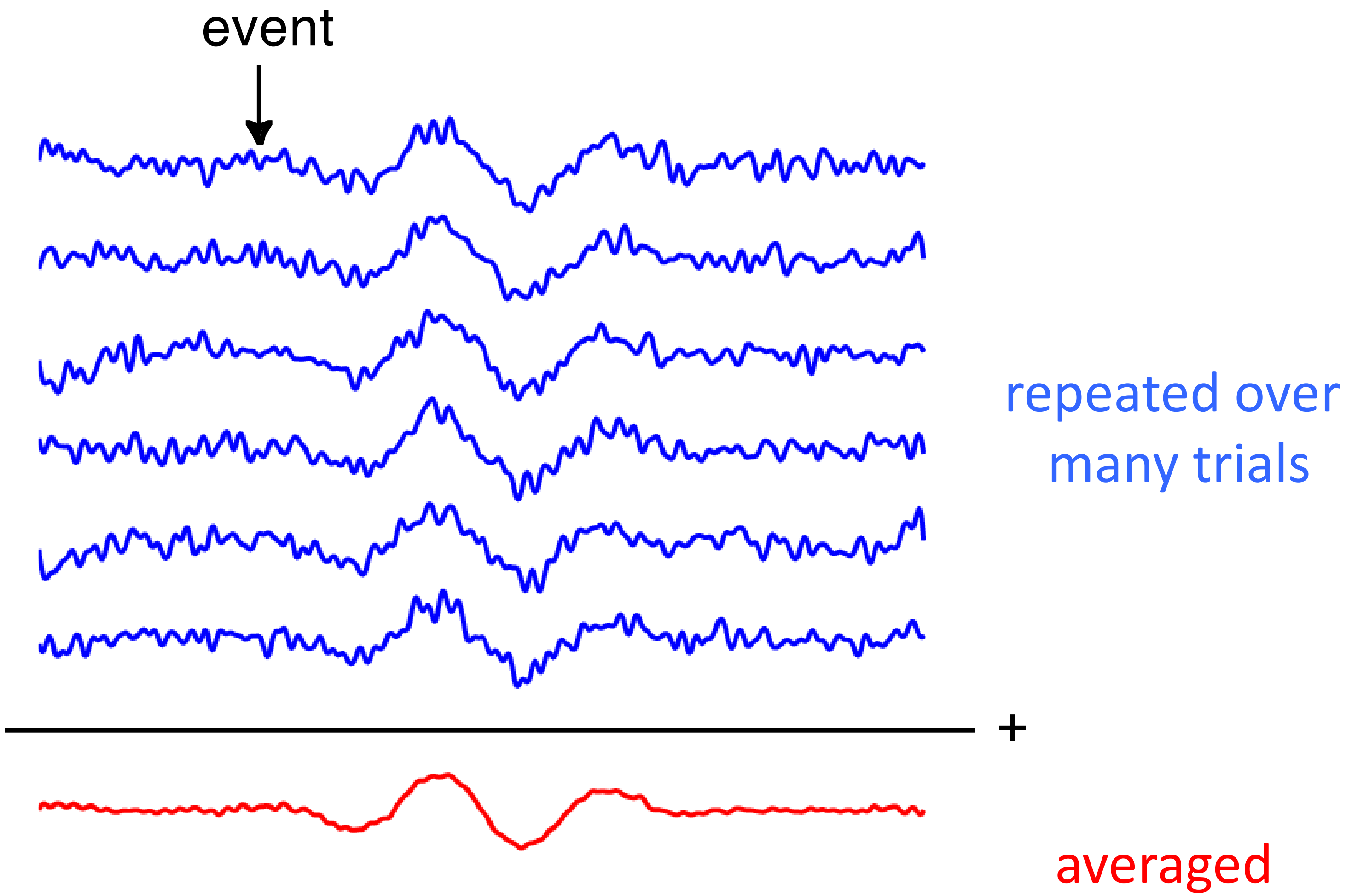
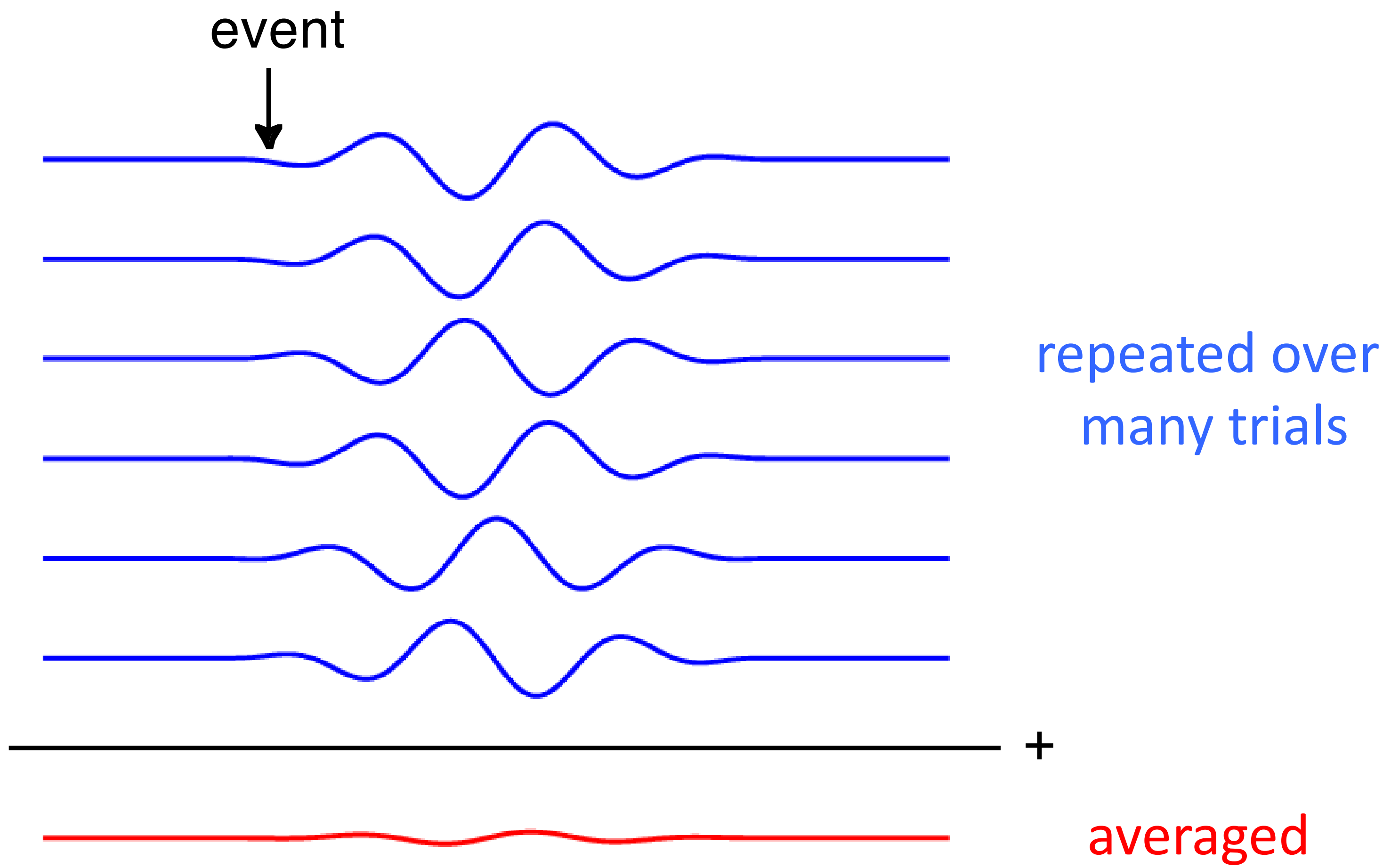
# Let’s recap evoked activity



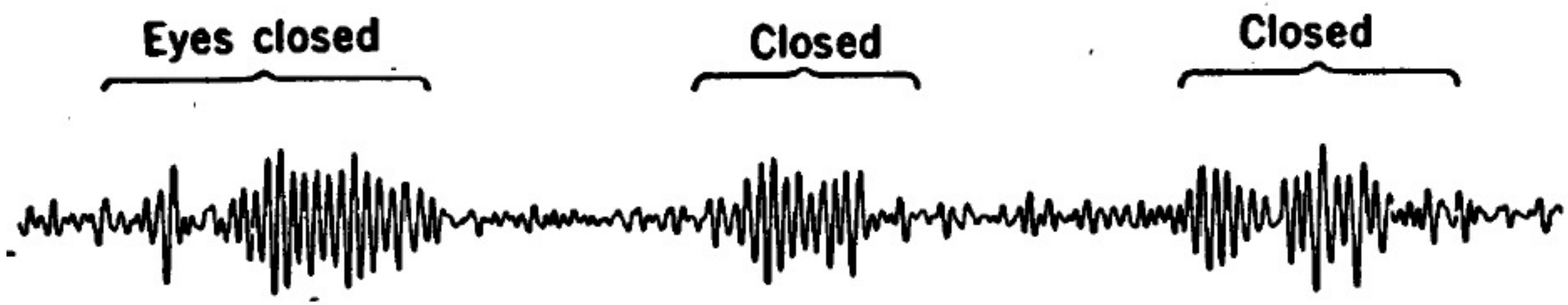
# Let's recap evoked activity



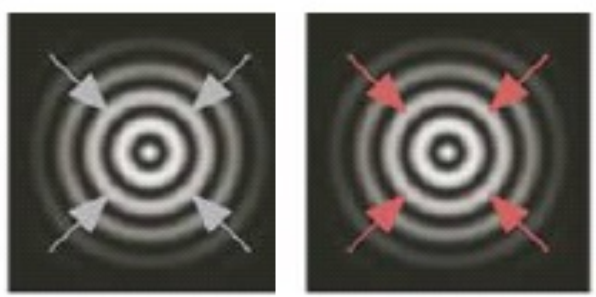
# What now?



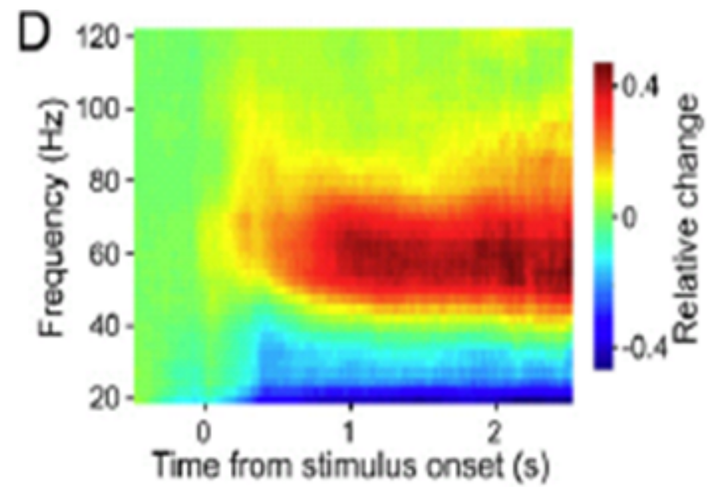
# Or what if the brain signal contains oscillatory components?




Cohen, 1972



Hoogenboom et al, 2006



# M/EEG signal characteristics considered during analysis

timecourse of activity
-> ERP

spectral characteristics
-> power spectrum

temporal changes in power
-> time-frequency response (TFR)

spatial distribution of activity over the head
-> source reconstruction

# Outline

Spectral analysis: going from time to frequency domain

Spectral leakage and (multi-)tapering

Time-frequency analysis

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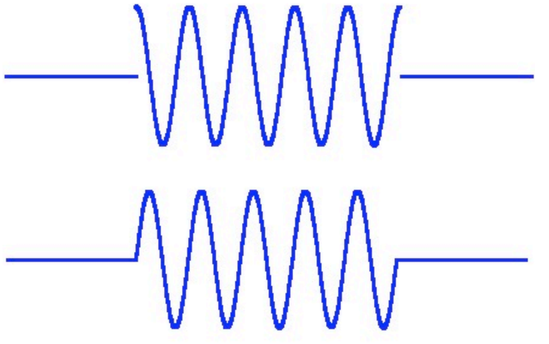
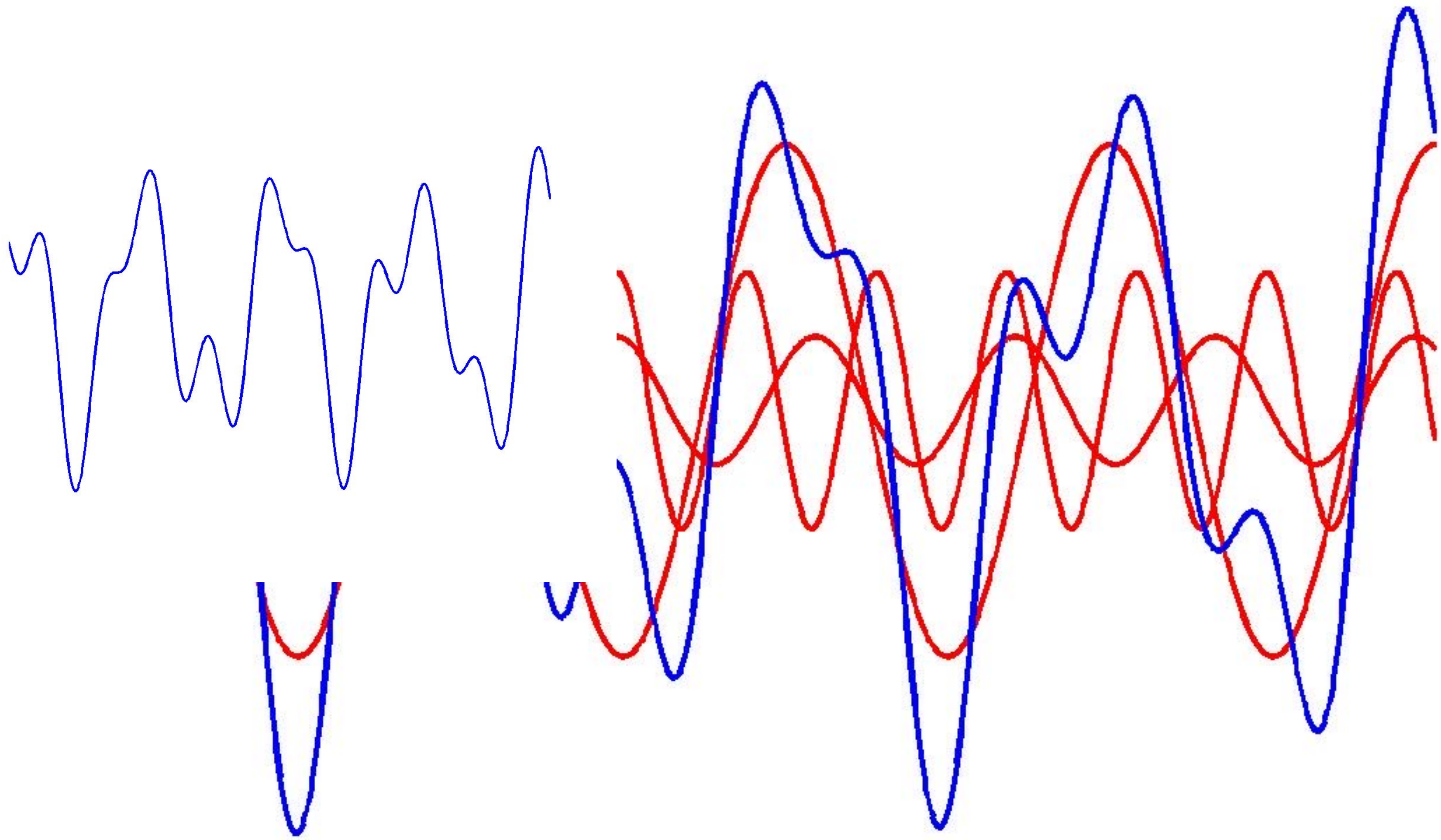
# Spectral analysis

Deconstructing a time domain signal into its constituent oscillatory components, a.k.a. Fourier analysis

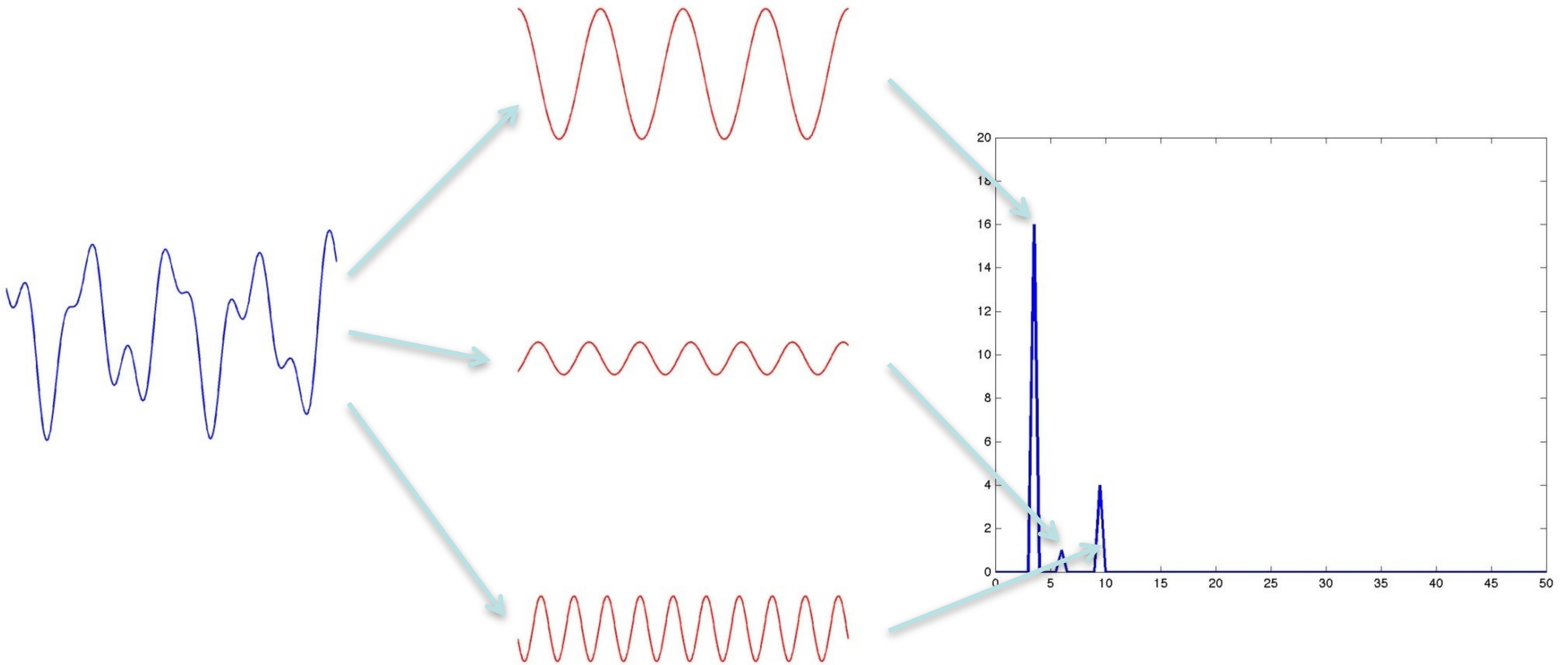
Using simple oscillatory functions: cosines and sines



# 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

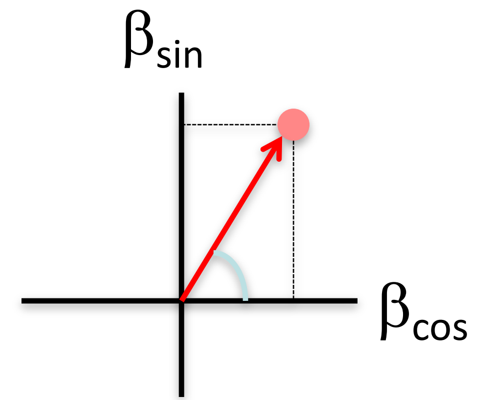
Using simple oscillatory functions: cosines and sines

Express signal as function of frequency, rather than time

Technique: Fourier transform

Concept: linear regression using oscillatory basis functions

# Spectral analysis ~ GLM




$Y = \beta * X$

X set of (orthogonal) basis functions

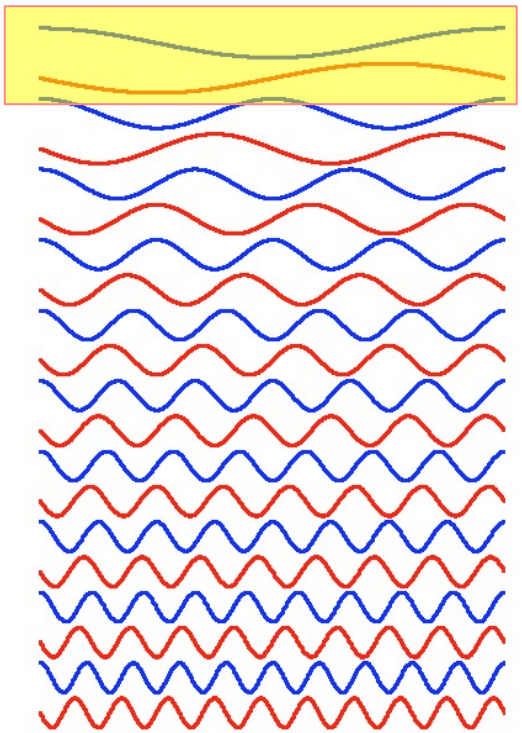
$\beta_i$ contribution of basis function i to the data.

$\beta$ for cosine and sine components for a given frequency map onto amplitude and phase estimate.

Going from N time points to N cosine/sine components

Each cosine/sine pair reflects 1 frequency bin so ~N/2 frequencies can be estimated

Frequencies correspond to integer number of cycles of basis functions in time window



# Time-frequency relation

Frequencies correspond to basis functions with integer number of cycles in time window (T), sampled in N discrete time steps of length $\Delta t$ (i.e. with sampling frequency $1/\Delta t$)

Rayleigh frequency = $1/T = \Delta f$ = frequency resolution

Time window: 1 s → Frequency bins: (0) 1 2 3 4 5 6 .. Hz

Time window: 0.2 s → Frequency bins: (0) 5 10 15 20 .. Hz

# Time-frequency relation

N basis functions -> N/2 frequencies

Frequency bins are spaced with $1/T = 1/(N*\Delta t)$

The highest frequency that can be resolved thus depends on the sampling frequency $1/\Delta t$

Nyquist frequency = $1/(2*\Delta t)$

Sampling freq 1 kHz

Time window 1 s

→

Frequencies:

(0) 1 2 ... 499 500 Hz

Sampling freq 400 Hz

Time window 0.25 s

→

Frequencies:

(0) 4 8... 196 200 Hz

# 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

Technique: Fourier transform

Concept: linear regression using oscillatory basis functions

Each oscillatory component has an amplitude and phase

Discrete and finite sampling constrains the frequency bins
-> spectral leakage

# Outline

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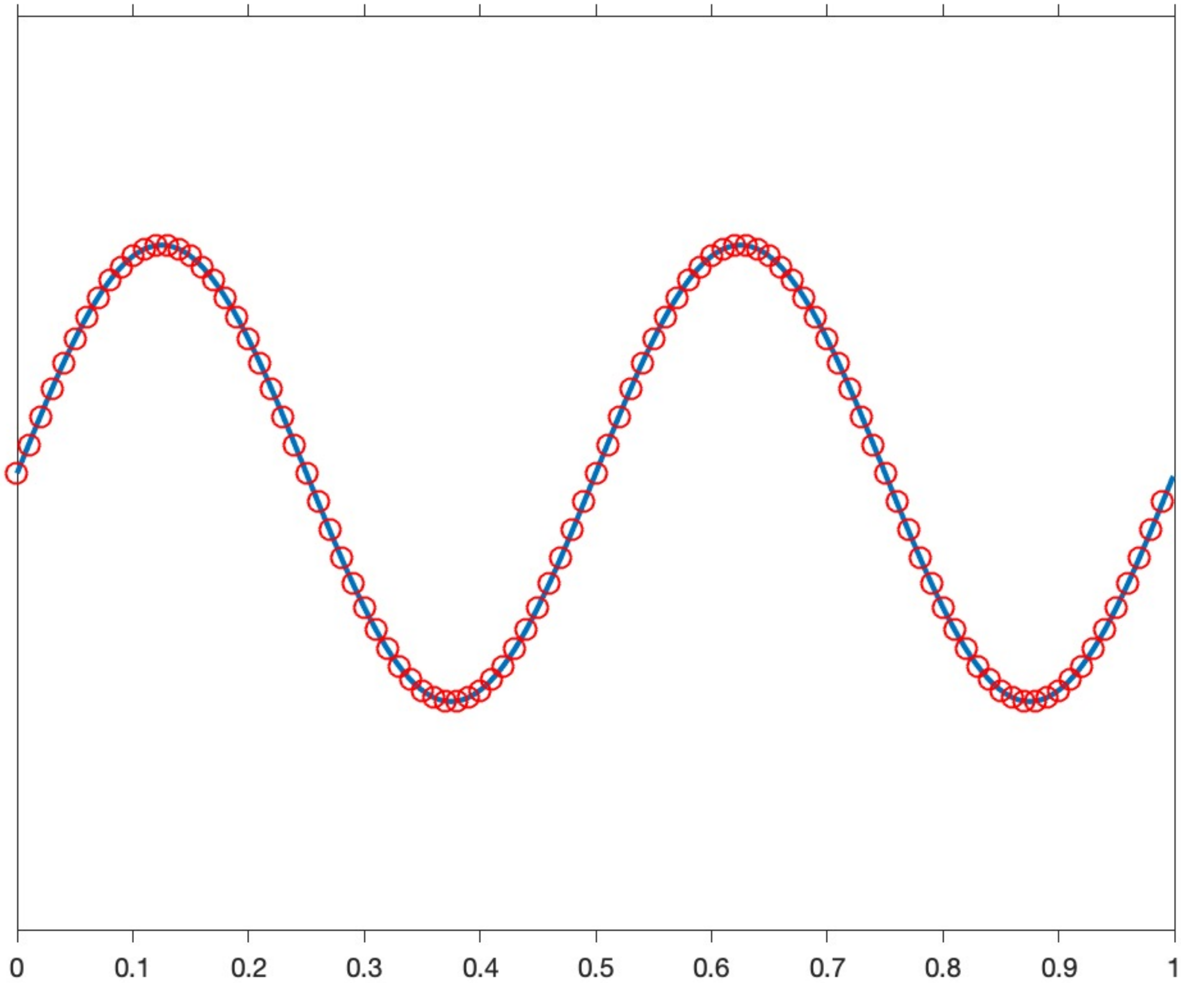
Spectral leakage and (multi-)tapering

Time-frequency analysis

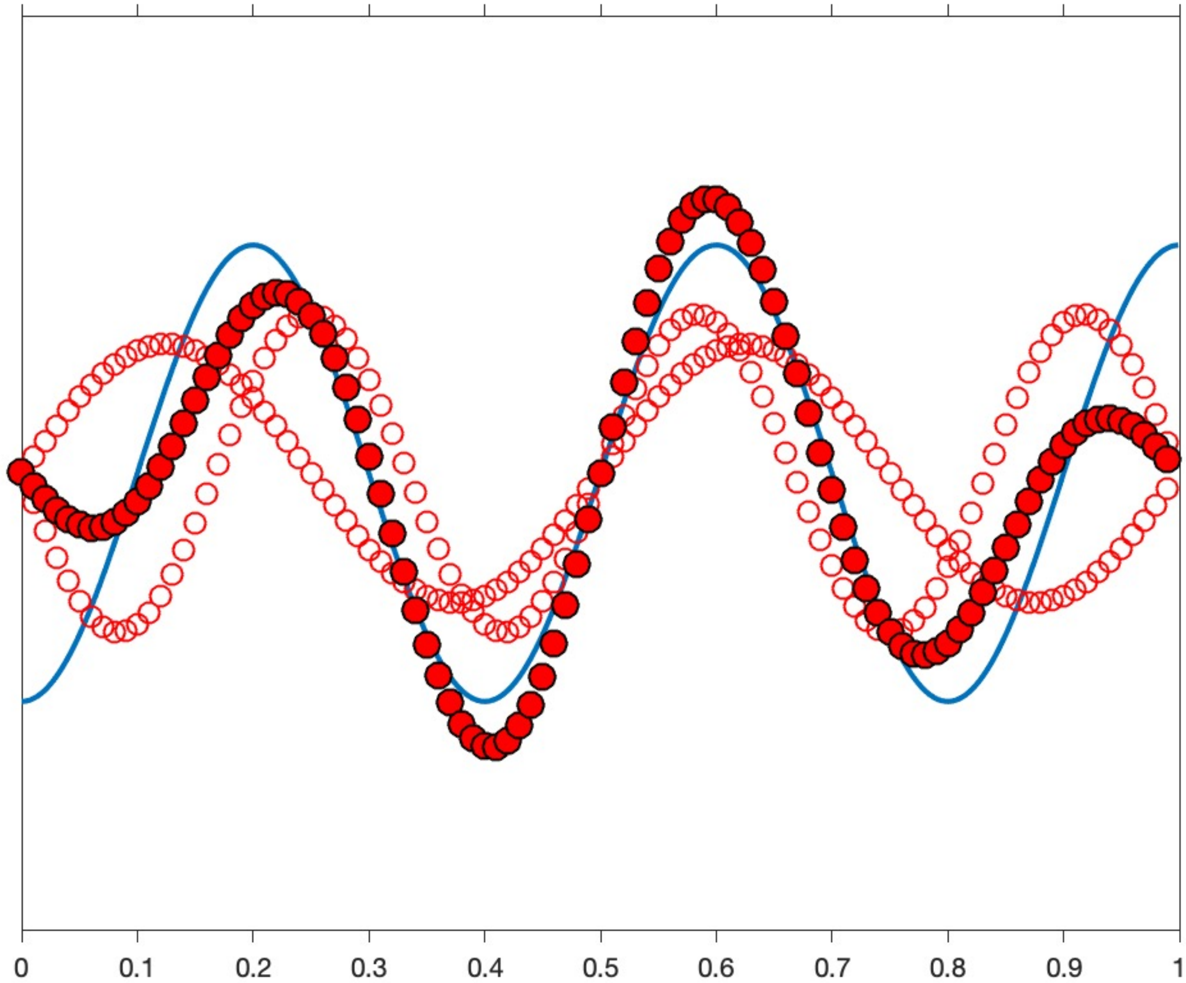
# Spectral leakage and tapering

- Signal components at frequencies not sampled with Fourier transform spread their energy to the sampled frequencies

# Spectral leakage

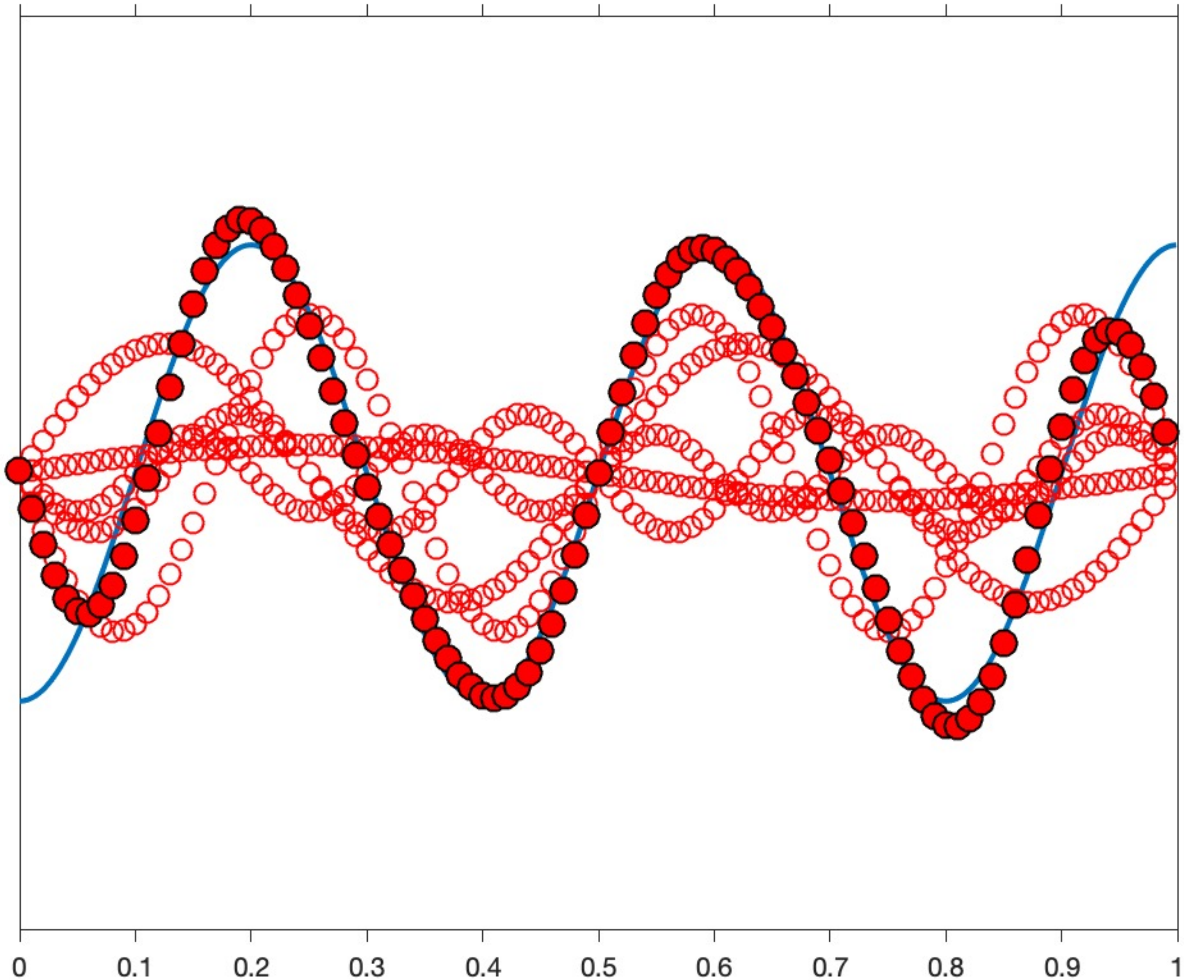


# Spectral leakage




Leakage can be 'local'

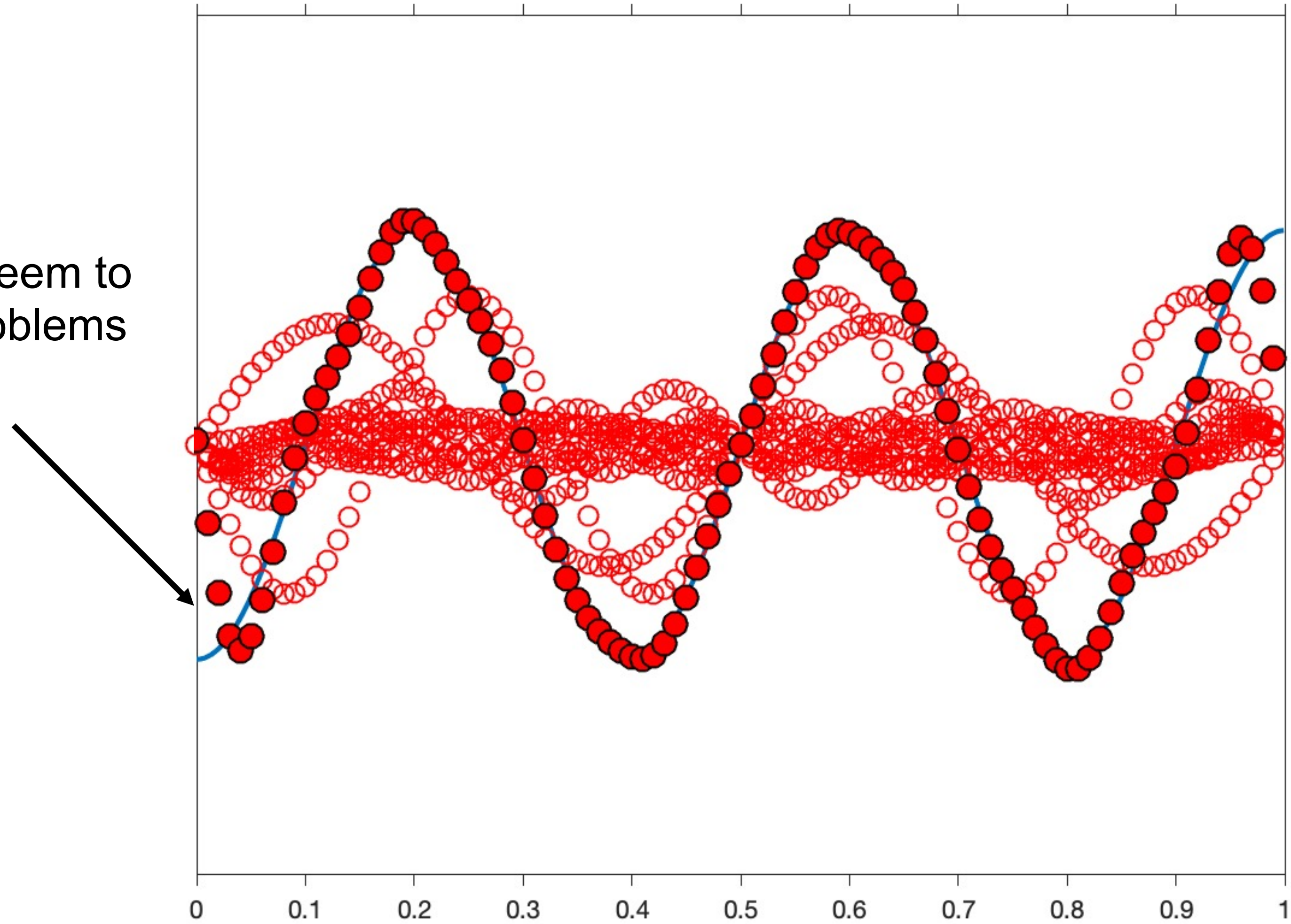
# Spectral leakage




Leakage is also ‘distant’

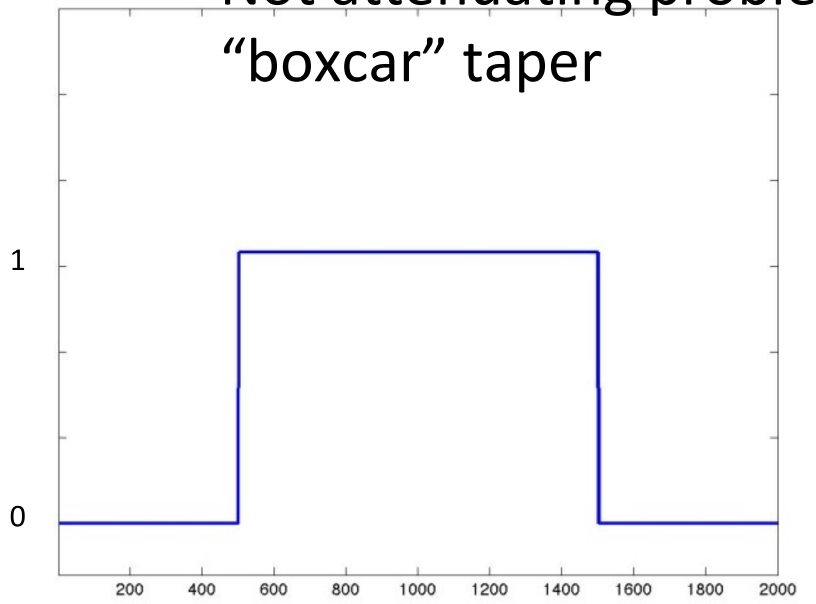
# Spectral leakage

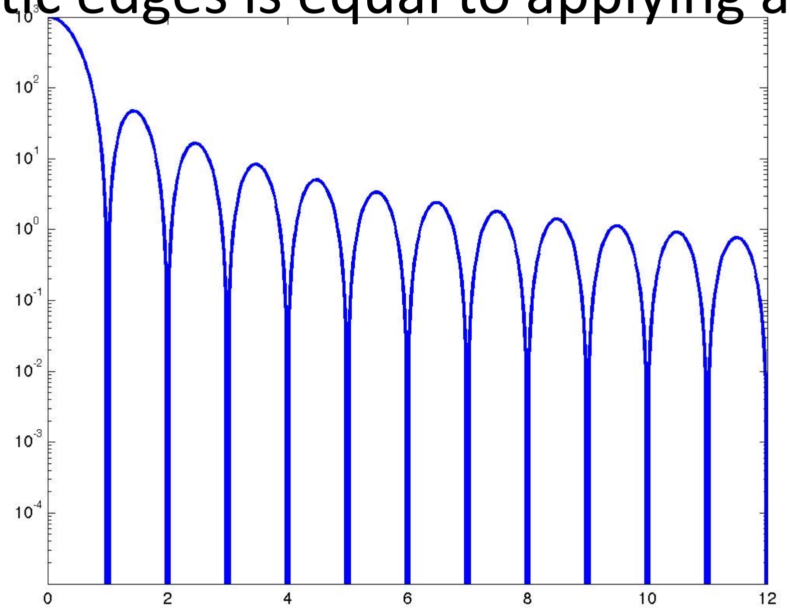
Edges seem to pose problems



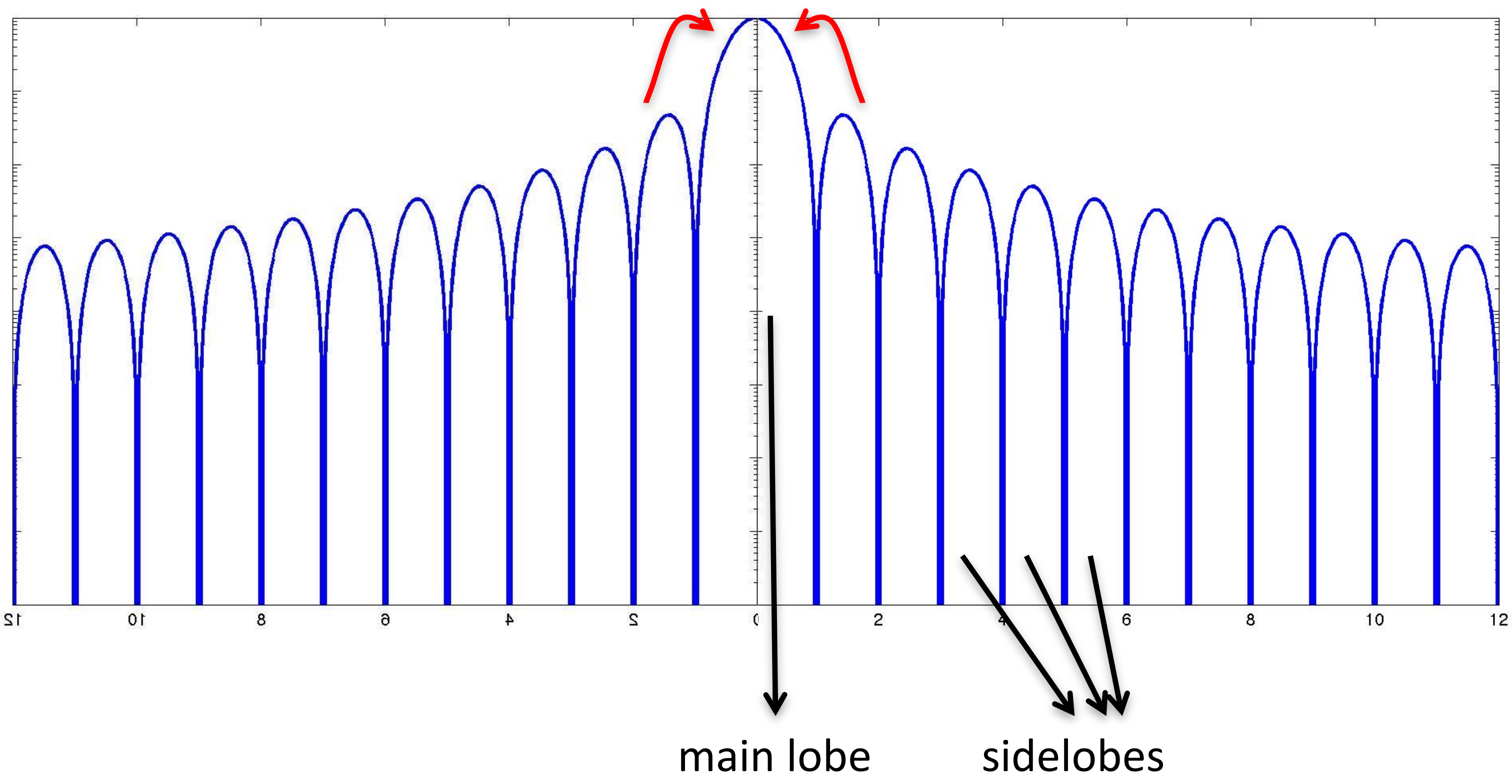
# Spectral leakage in the frequency domain

- Signal components at frequencies not sampled with Fourier transform spread their energy to the sampled frequencies
- To fit edges, many basis functions may be needed (lot of distant spectral leakage)
- Not attenuating problematic edges is equal to applying a "boxcar" taper



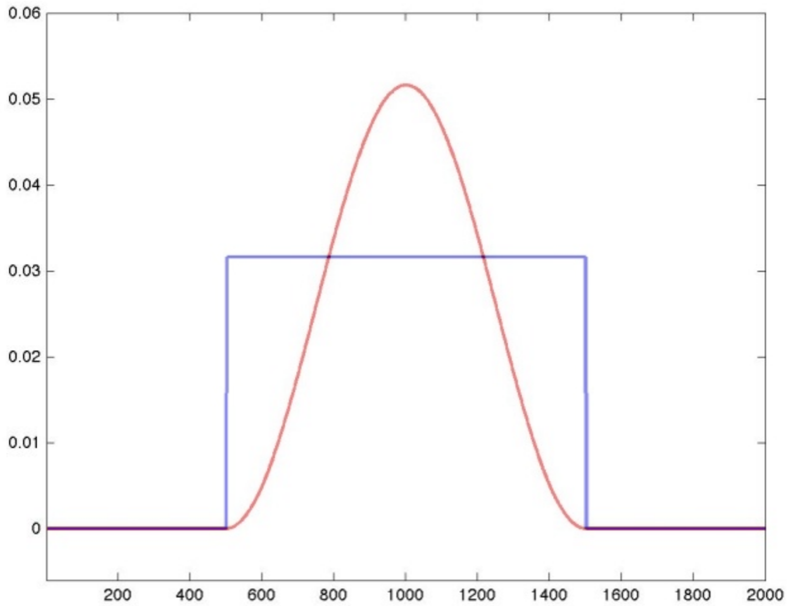



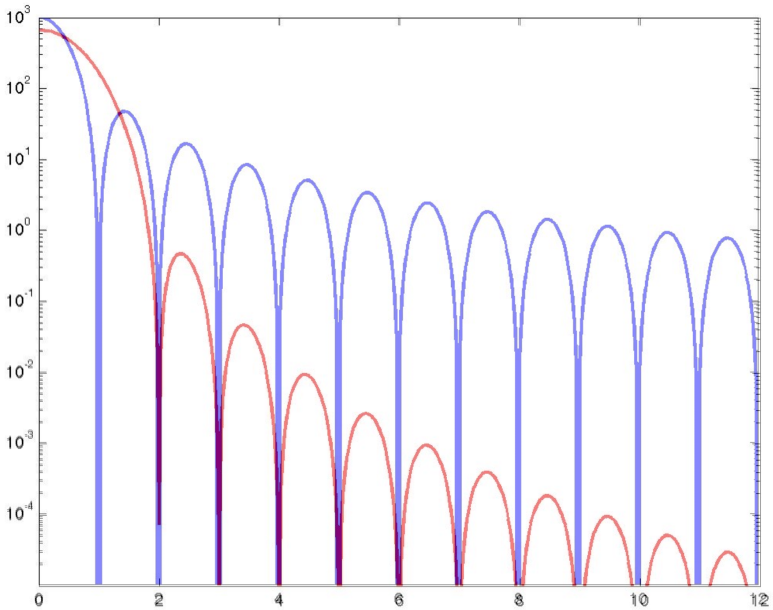
# Spectral leakage in the frequency domain



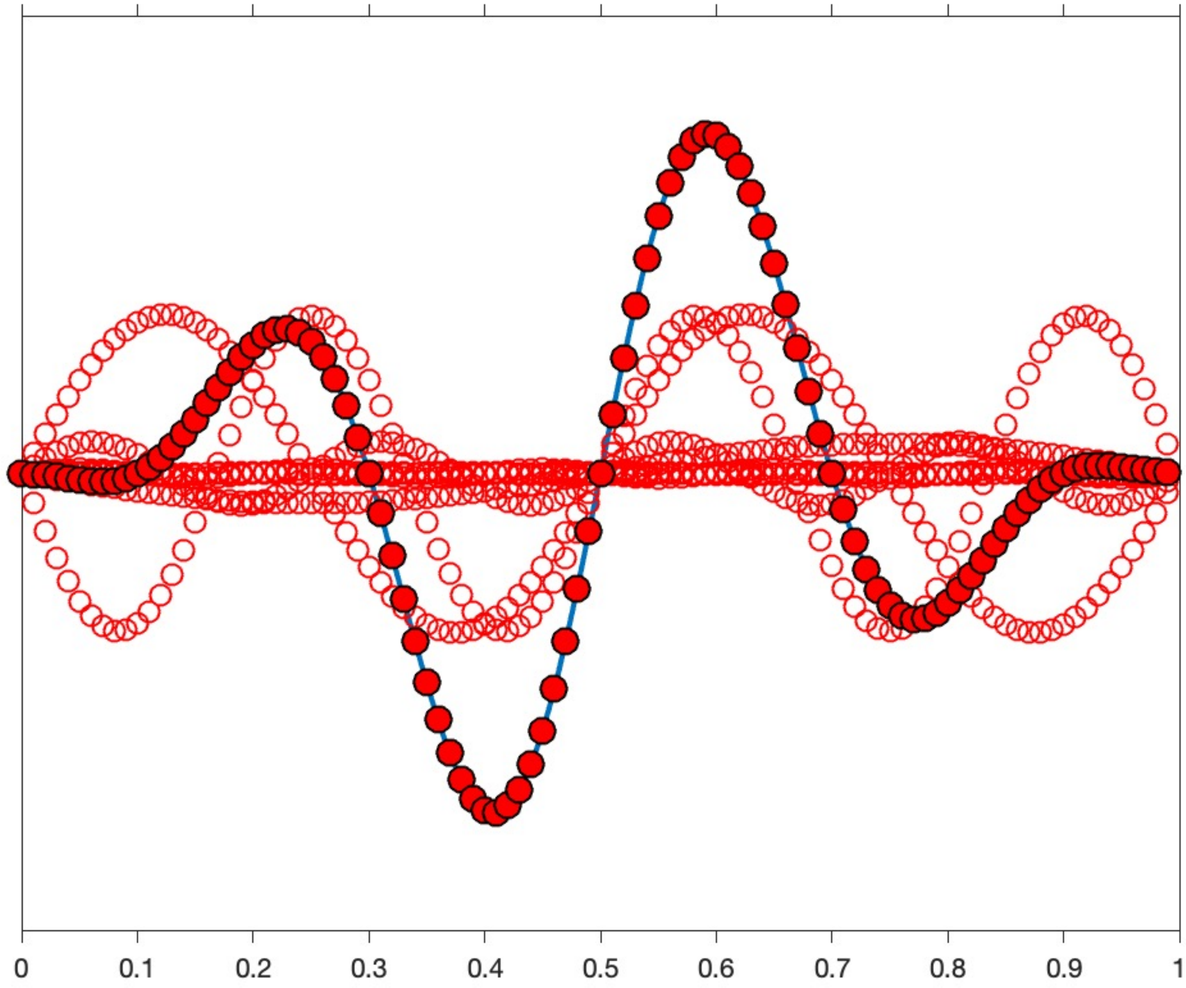
# Spectral leakage and tapering

- Tapering = attenuating potentially problematic edges of the signal by multiplication with a ‘taper function’

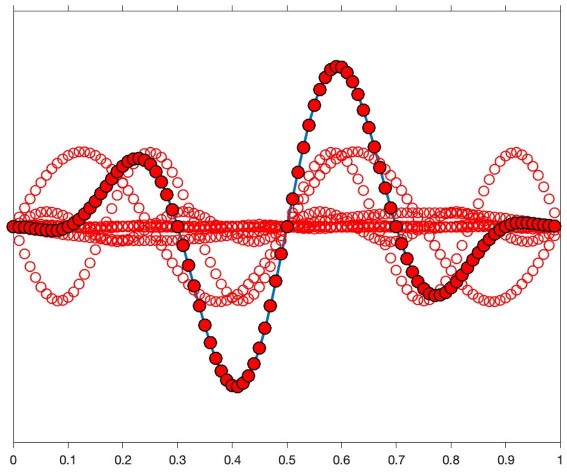


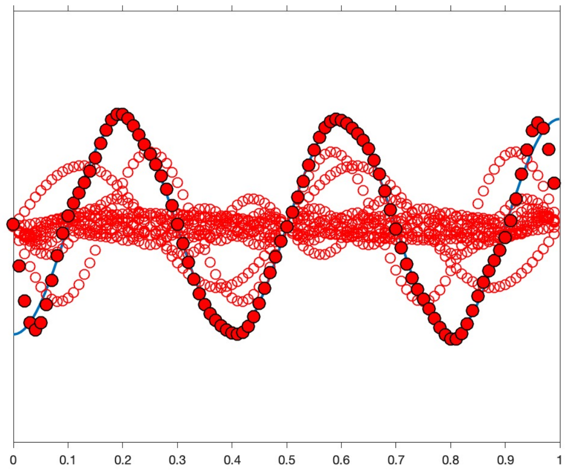



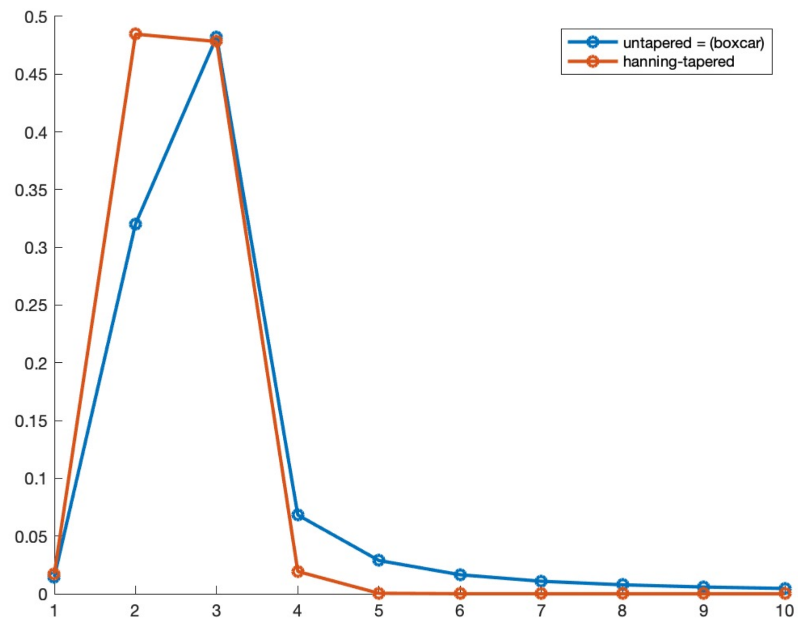
# Spectral leakage and tapering



# Spectral leakage and tapering



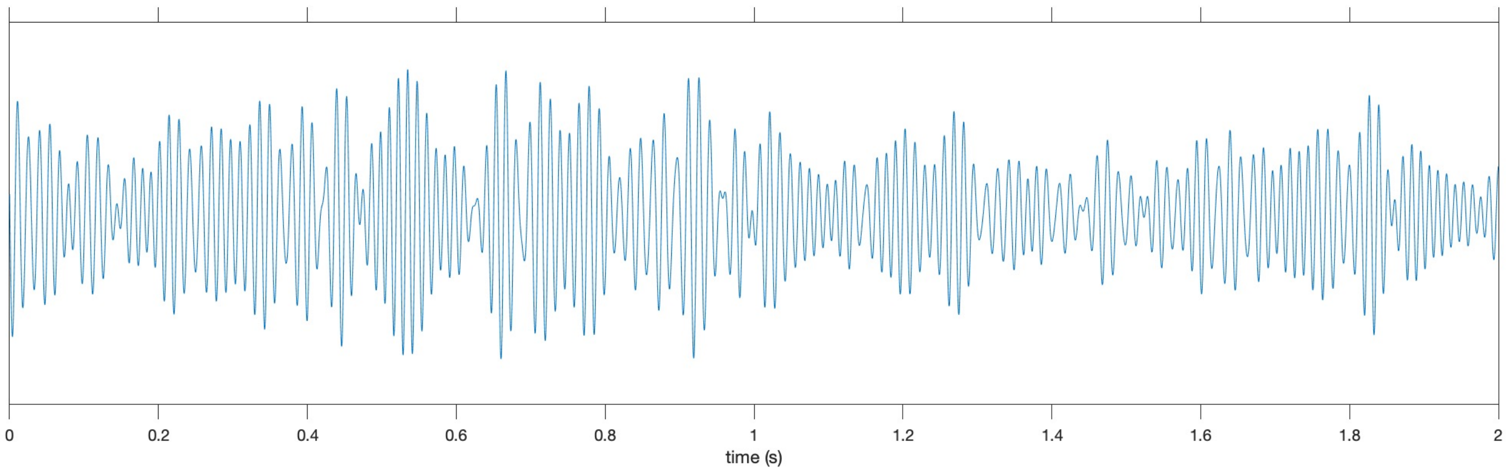
# Multitapers

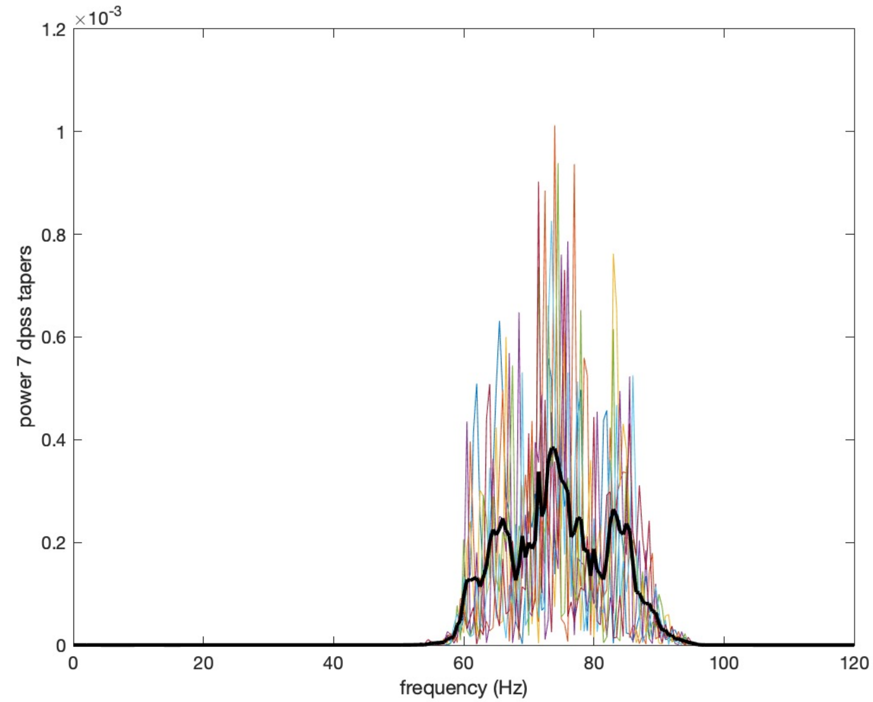
Make use of more than one taper and combine their leakage properties

Used for smoothing in the frequency domain

Instead of “smoothing” one can also say “controlled leakage”

# Multitapered spectral analysis

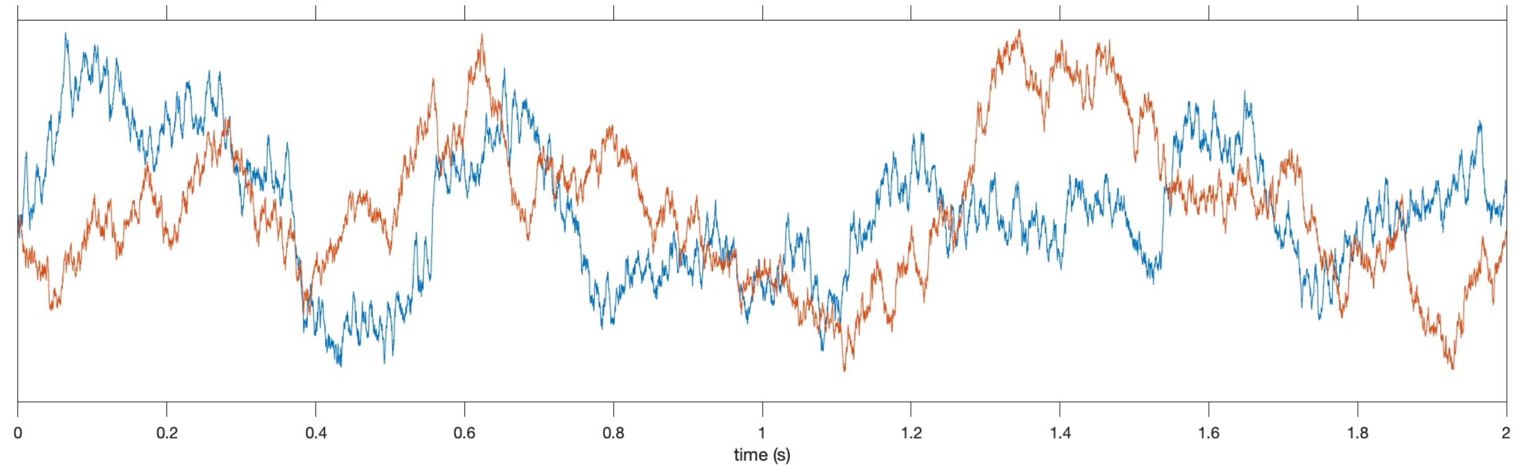


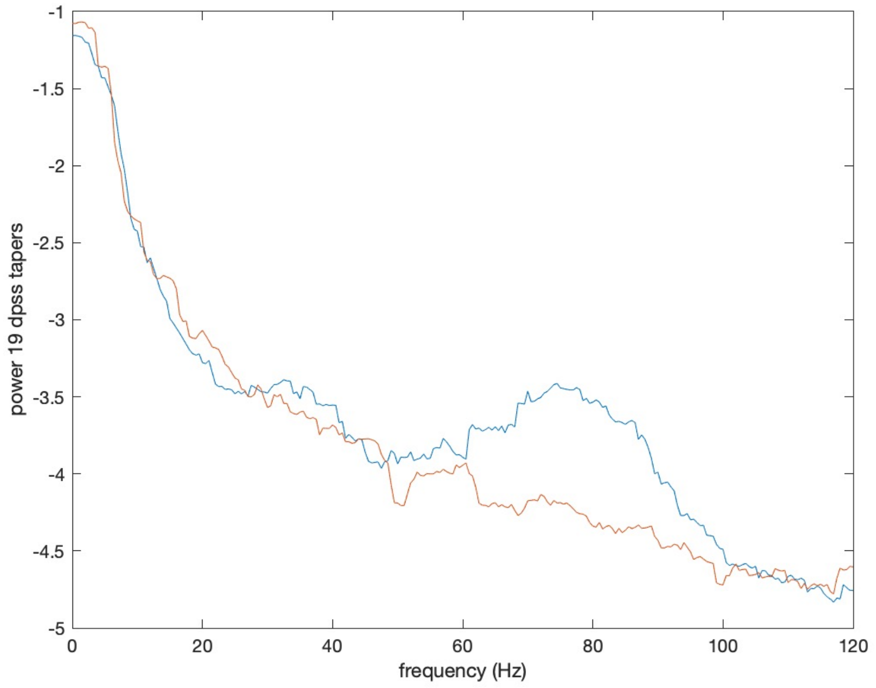






Pesaran, 1999, Biophys J

# Multitapered spectral analysis






Pesaran, 1999, Biophys J

# Multitapers

Multitapers are useful for reliable estimation of frequency components with a bandwidth > spectral resolution

Low frequency components are better estimated using a single (Hanning) taper

```
%estimate low frequencies

cfg  = [];
cfg.method = 'mtmfft';
cfg.foilim = [1 30];
cfg.taper  = 'hanning';
      .
      .
      .
freq=ft_freqanalysis(cfg, data);
```

```
%estimate high frequencies

cfg  = [];
cfg.method    = 'mtmfft';
cfg.foilim    = [30 120];
cfg.taper     = 'dpss';
cfg.tapsmofrq = 8;
      .
      .
freq=ft_freqanalysis(cfg, data);
```

# Outline

Spectral analysis: going from time to frequency domain

Spectral leakage and (multi-)tapering

Time-frequency analysis

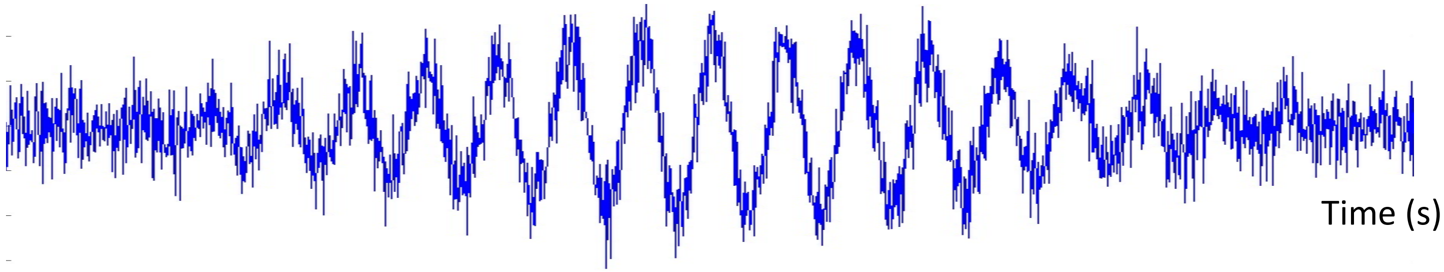
# Time-frequency analysis

Typically, brain signals are not 'stationary'

- Divide the measured signal in shorter time segments and apply Fourier analysis to each signal segment

```
cfg  = [];
cfg.method = 'mtmconvol';
      .
      .
      .
freq = ft_freqanalysis(cfg, data);
```

# Time frequency analysis



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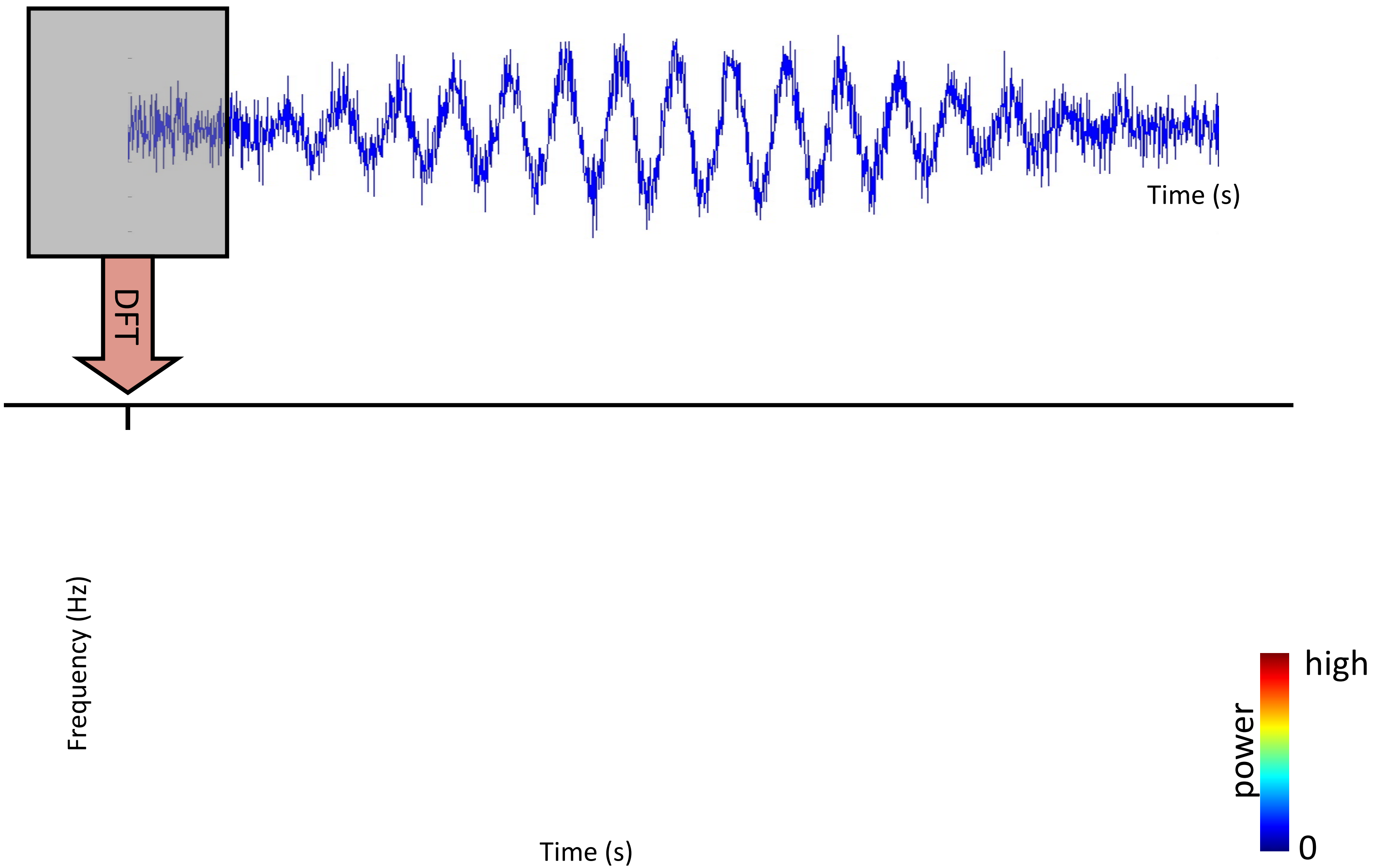

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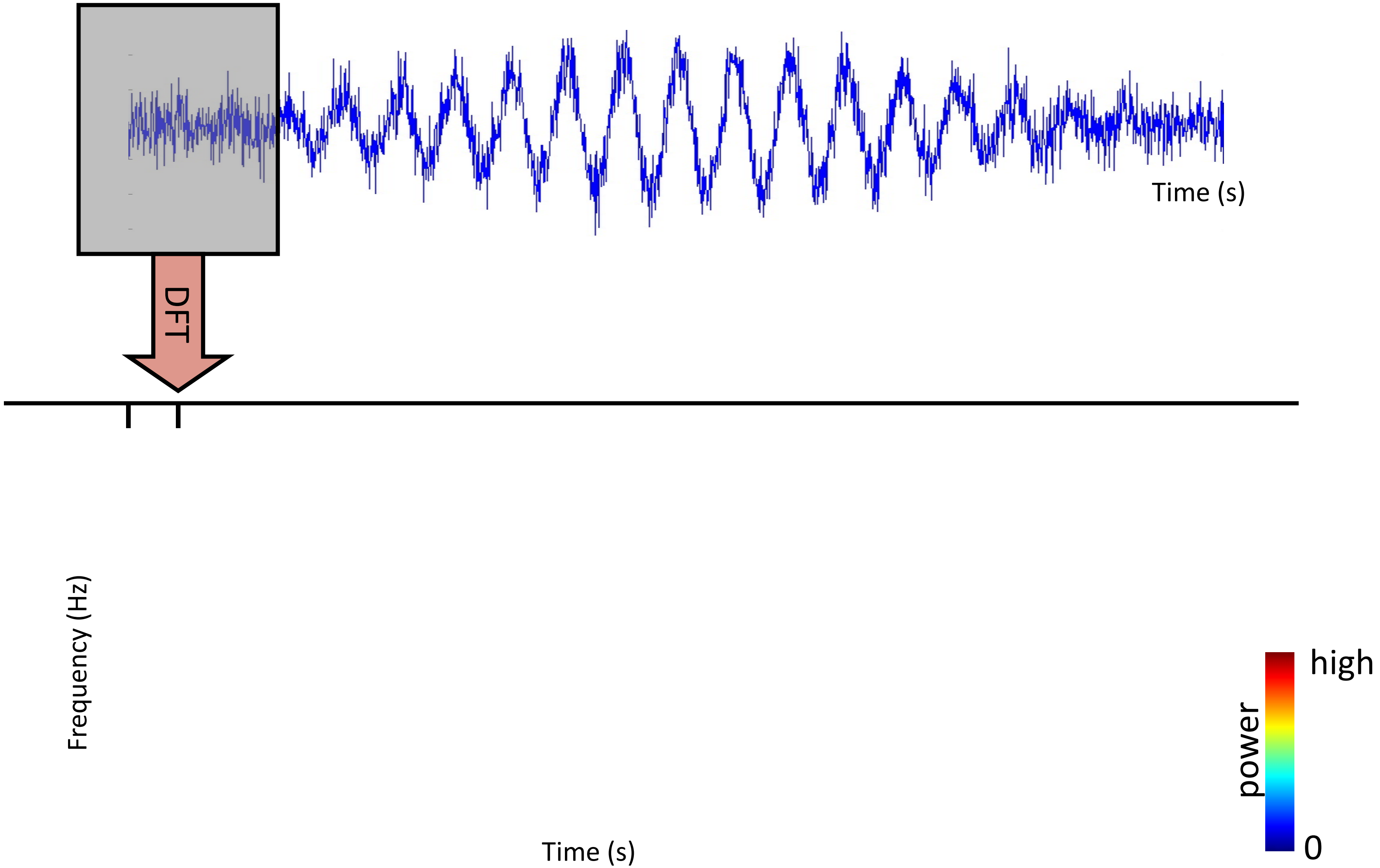

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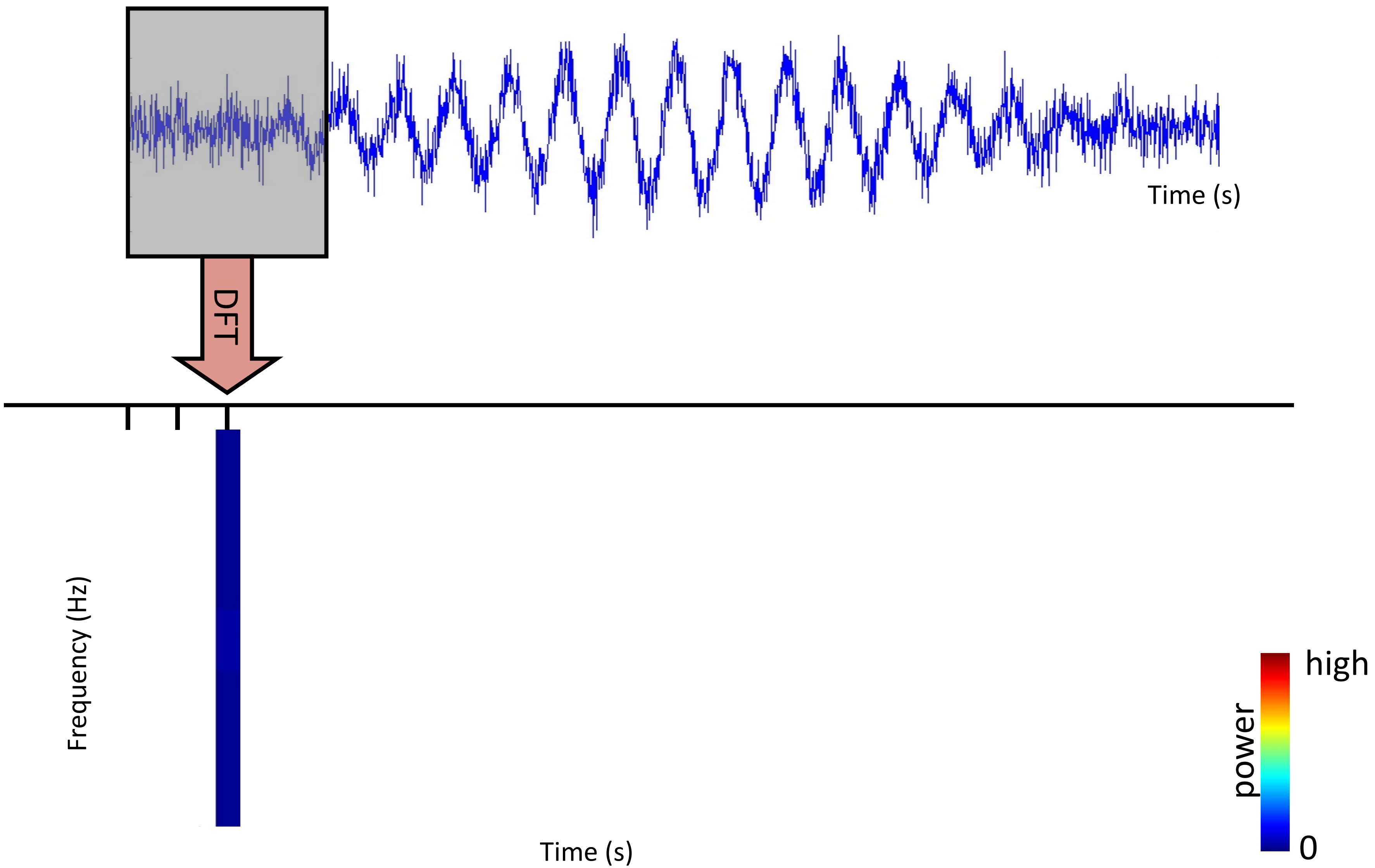

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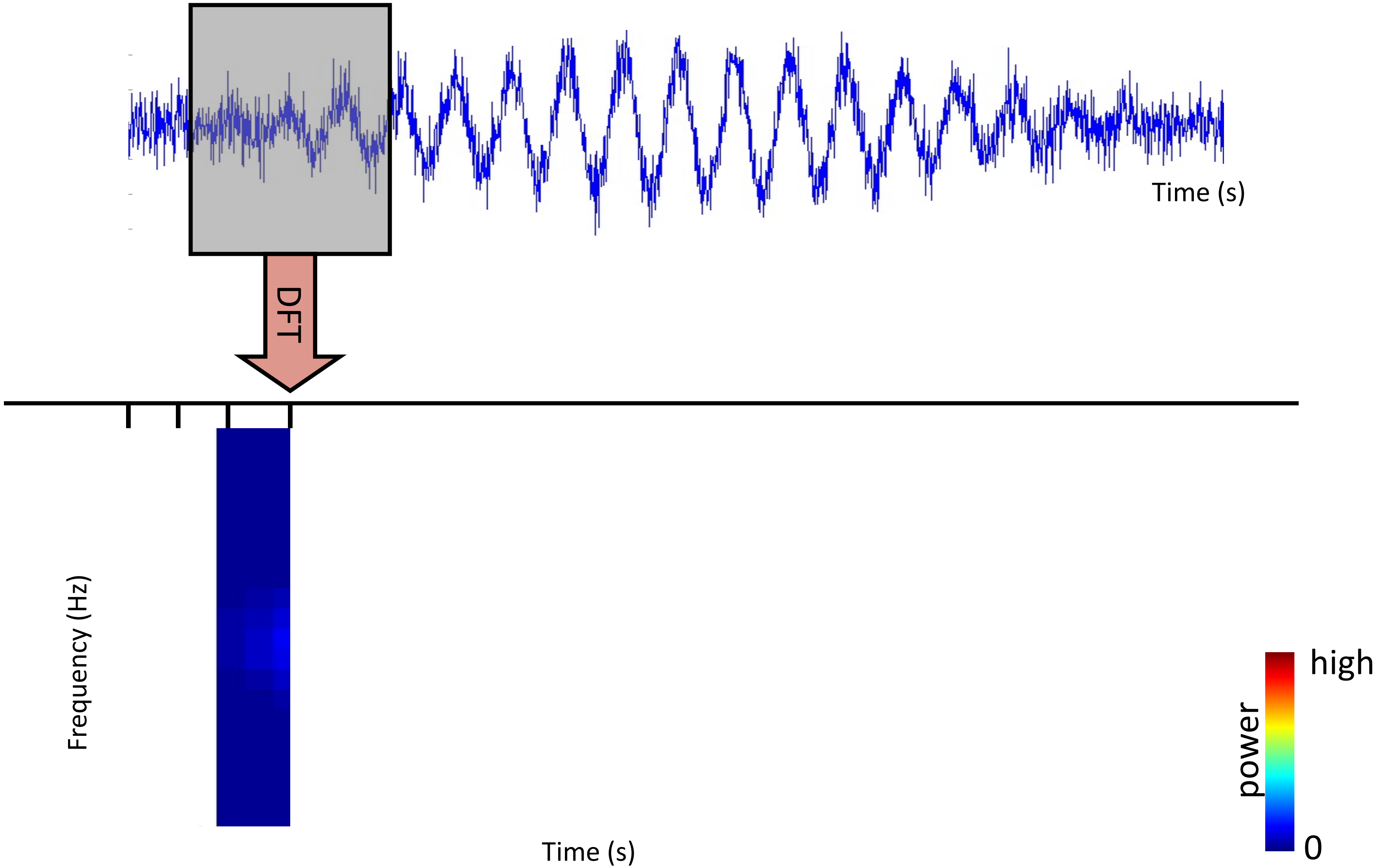

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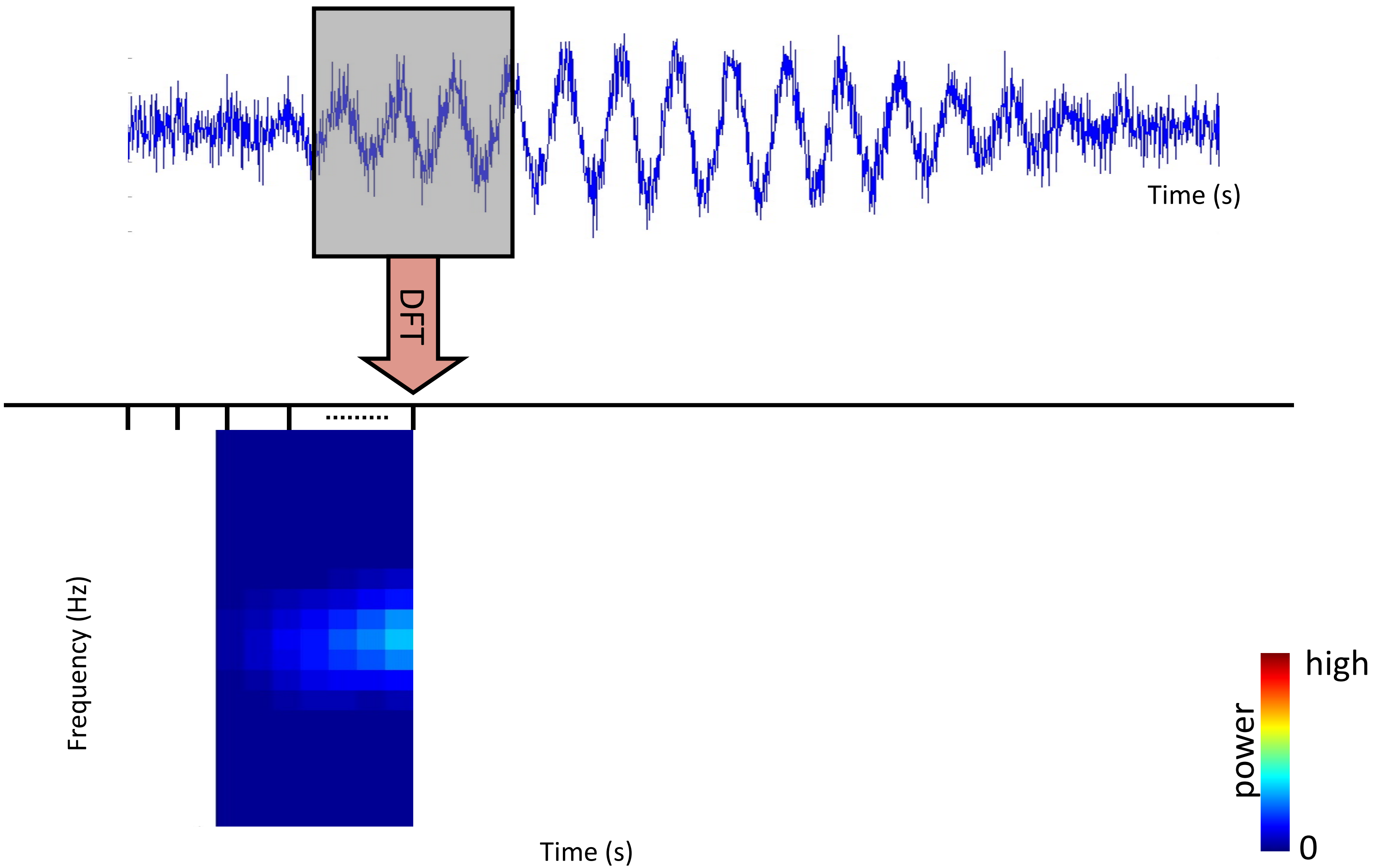
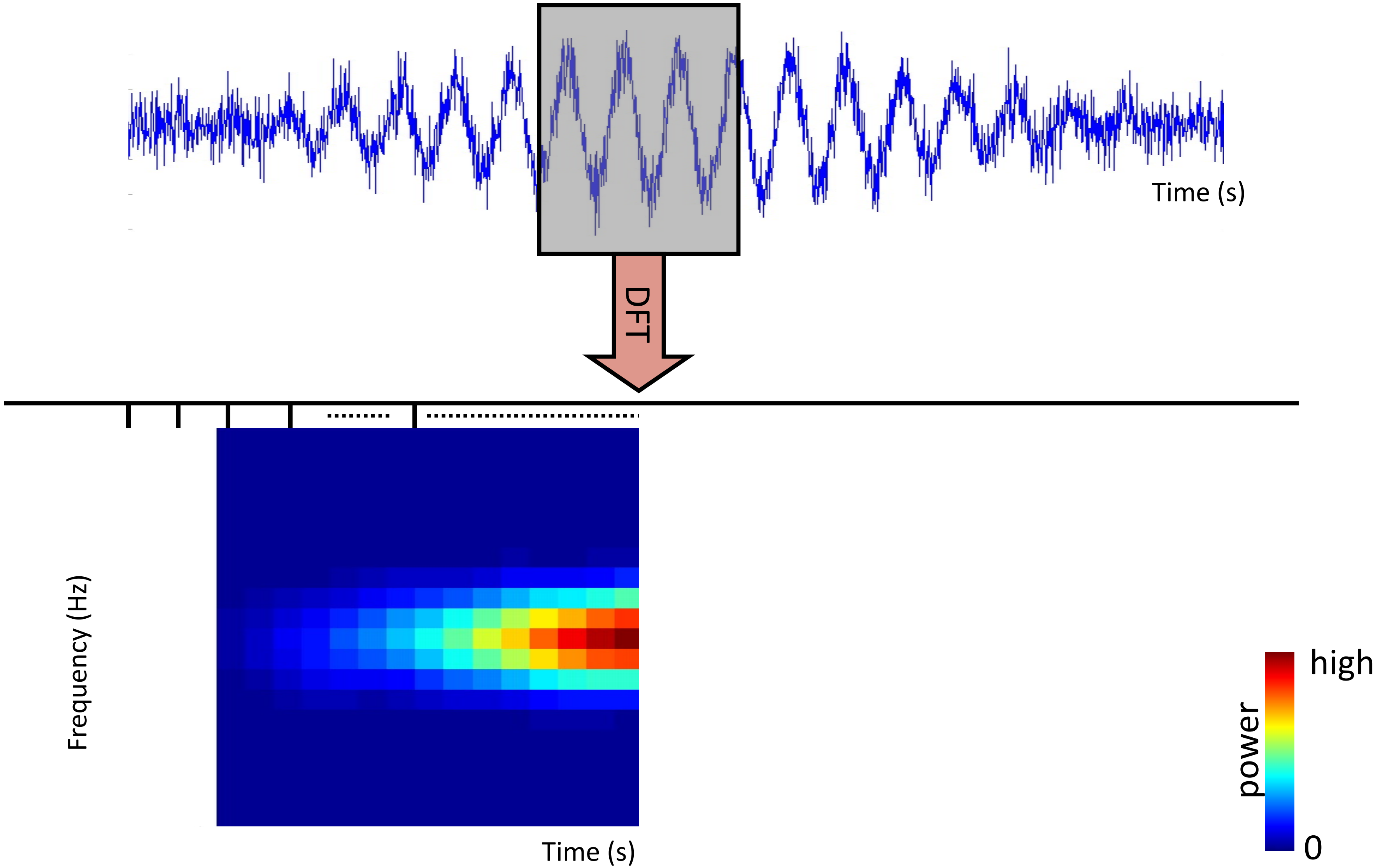
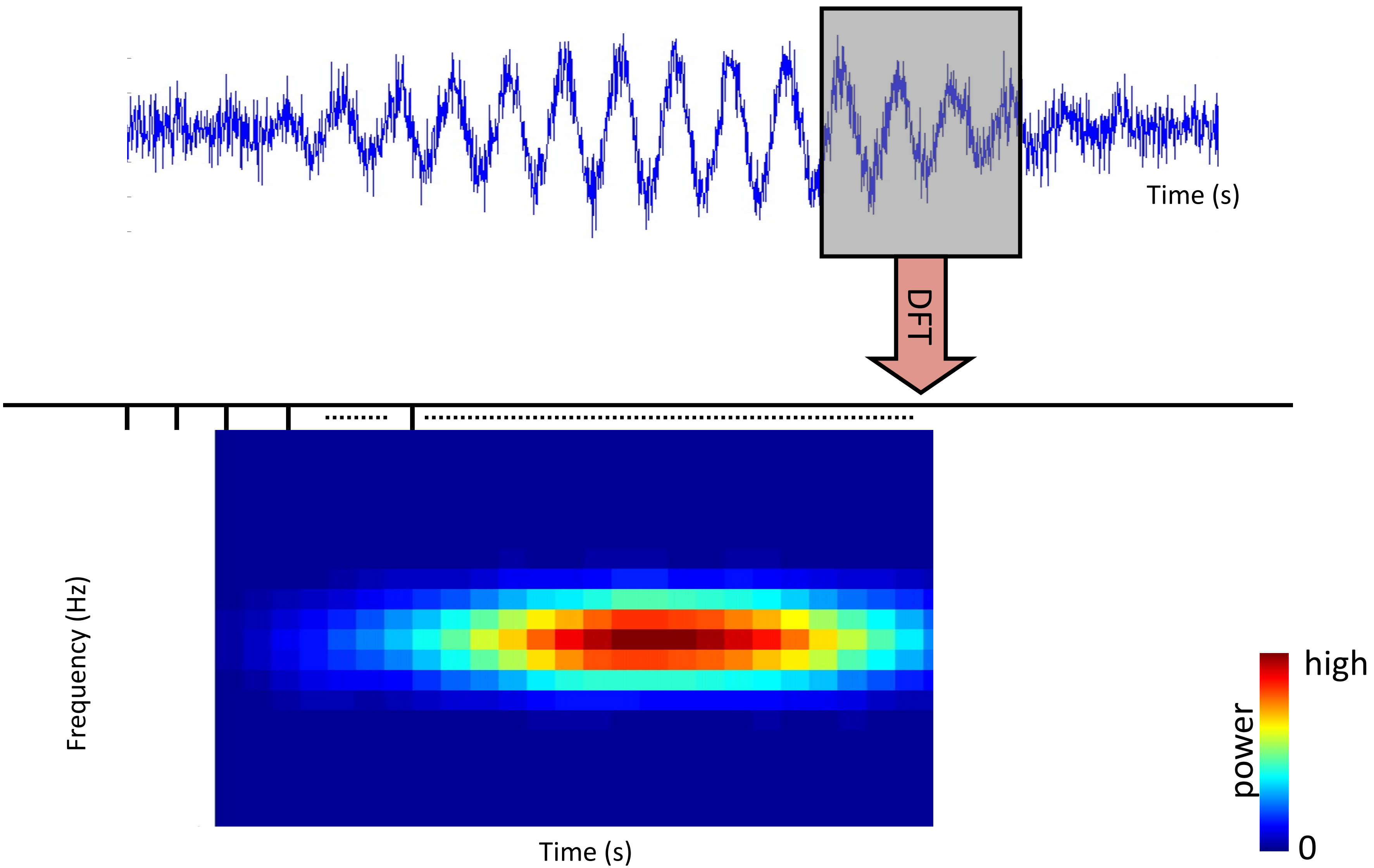


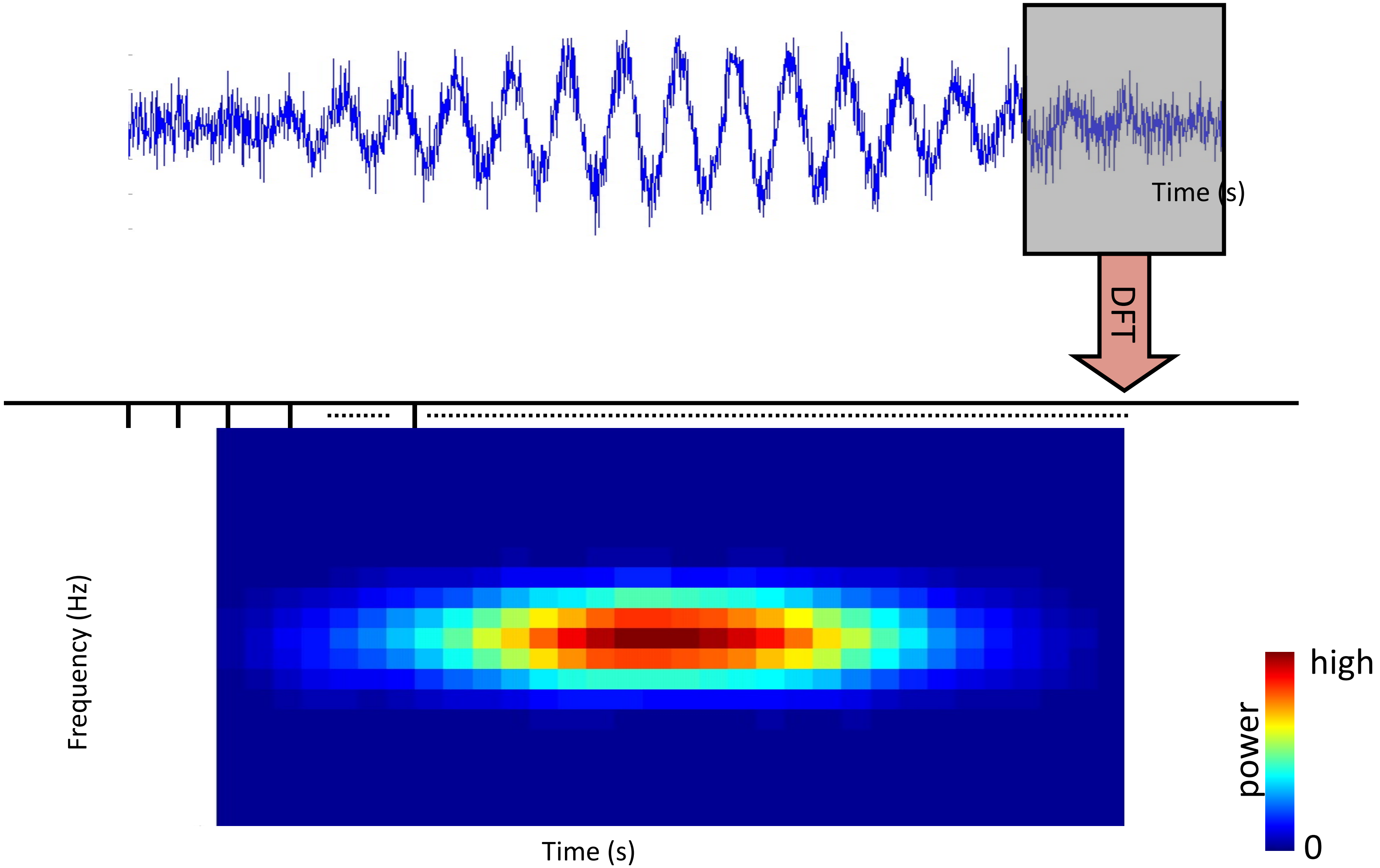
# Time frequency analysis



# Time frequency analysis



# Time frequency analysis



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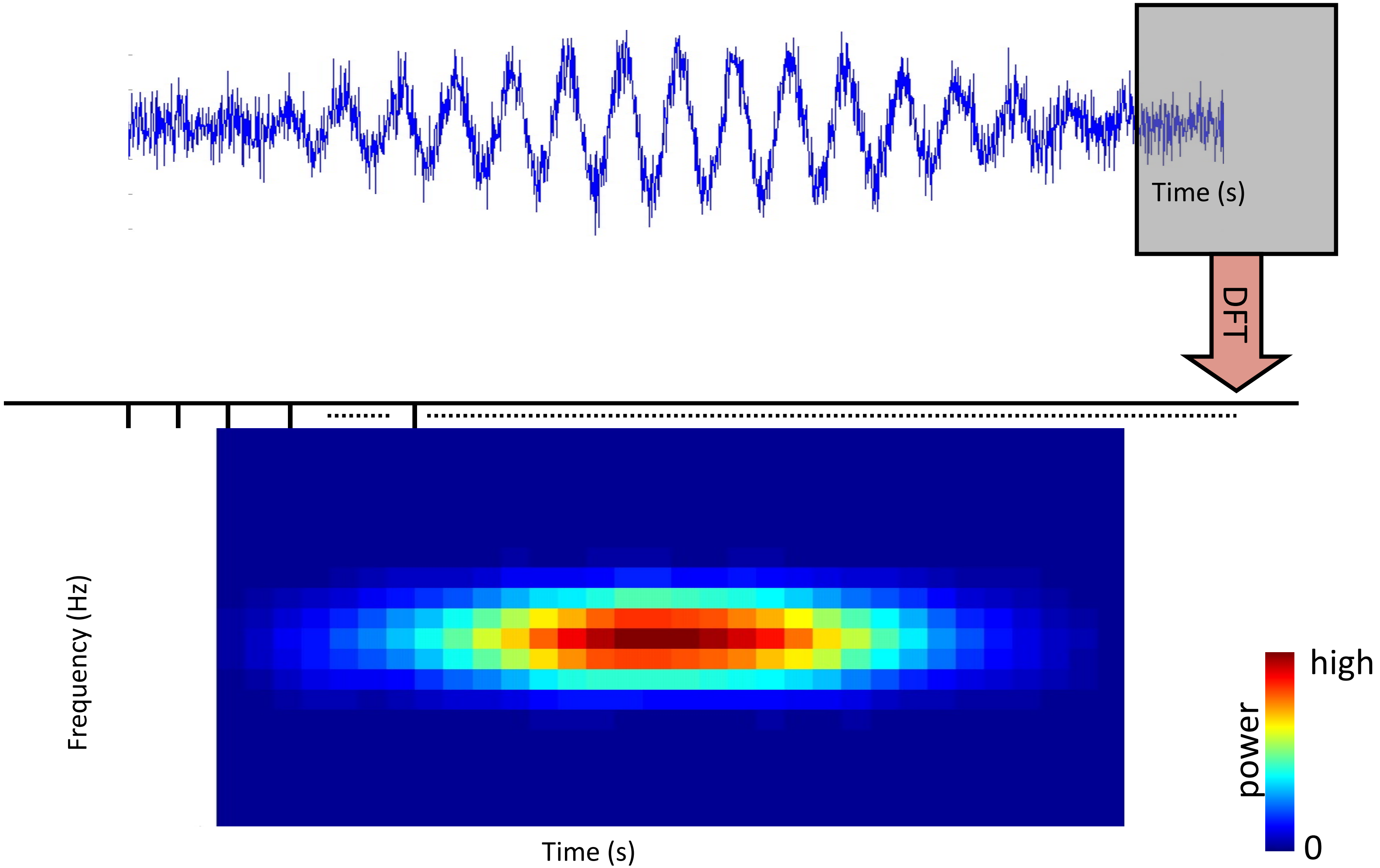
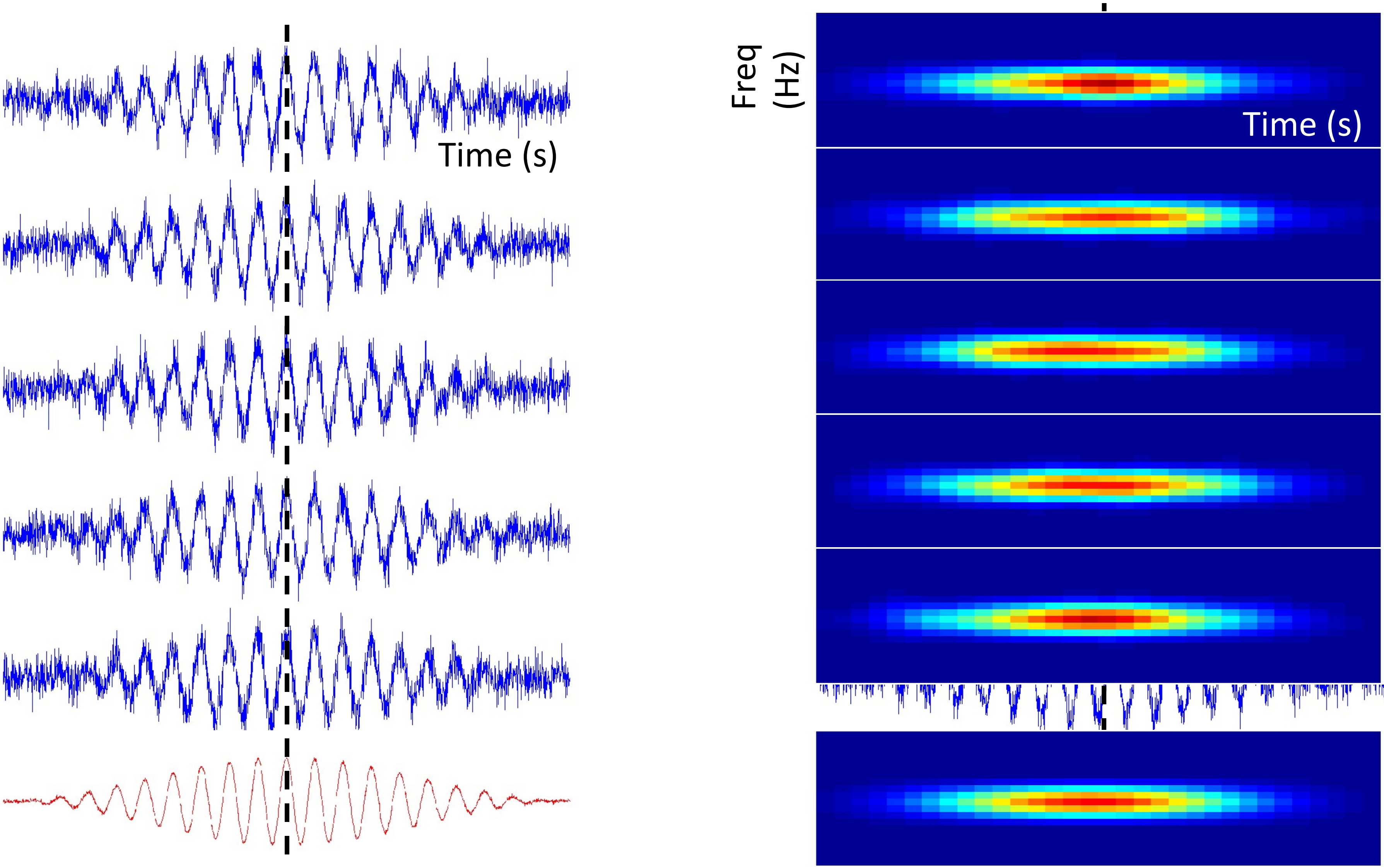
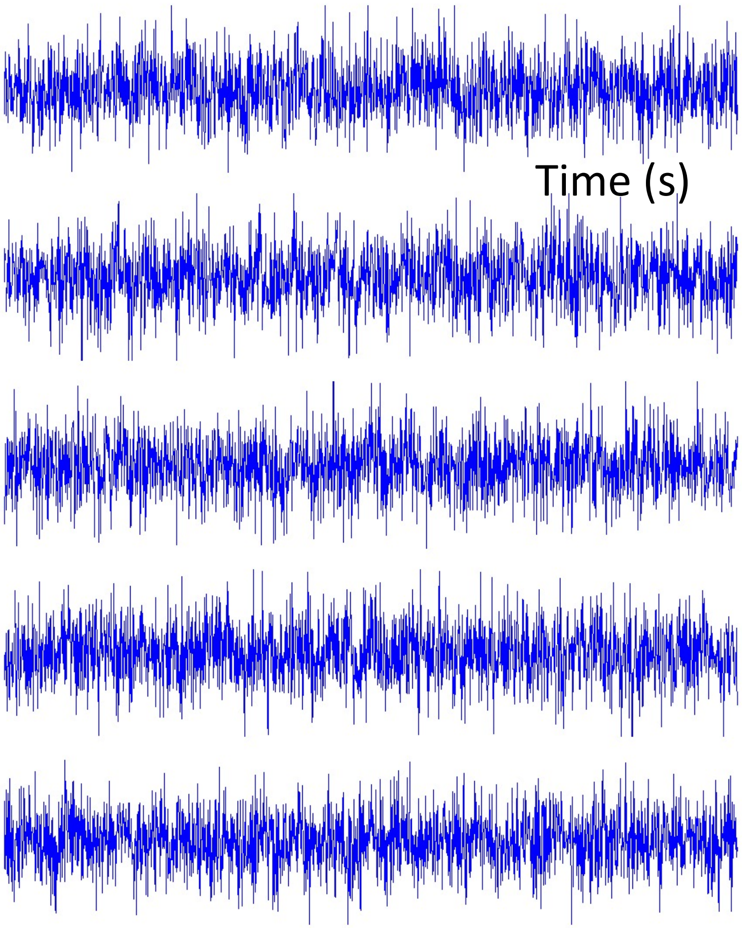
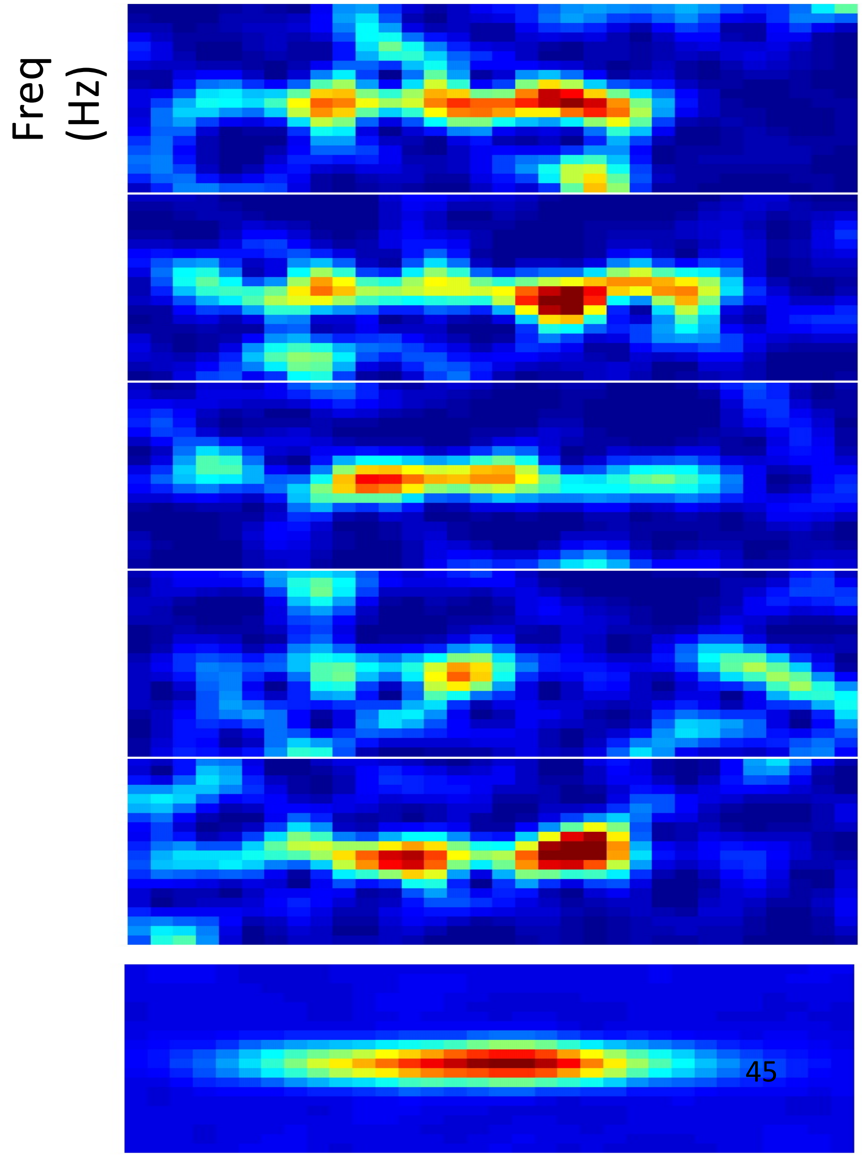


# Evoked versus induced activity

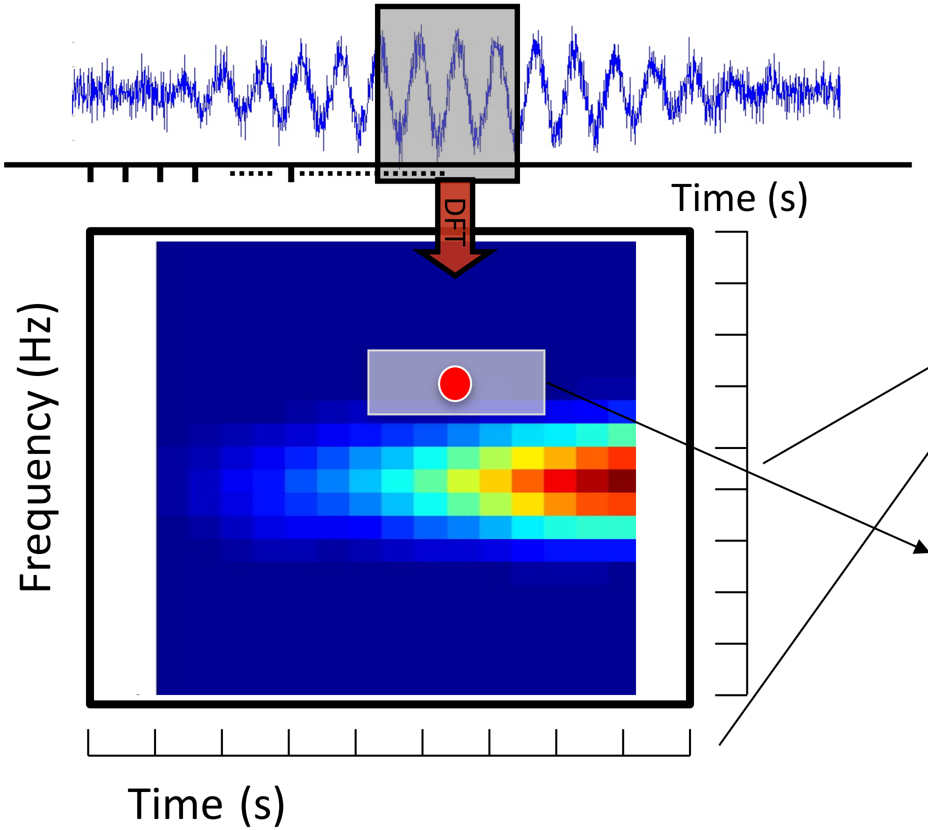


# Noisy signal -> many trials needed



# The time-frequency plane



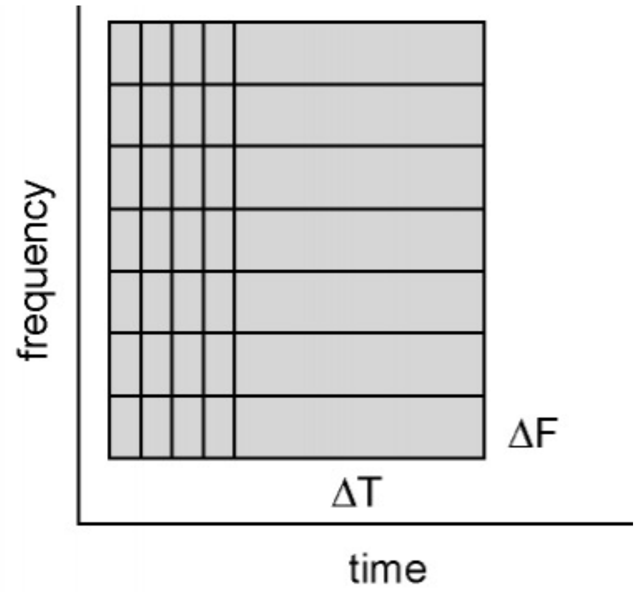

```
cfg          = [];
cfg.method = 'mtmconvol';



freq = ft_freqanalysis(cfg,data)
```

# The time-frequency plane

The division is 'up to you'

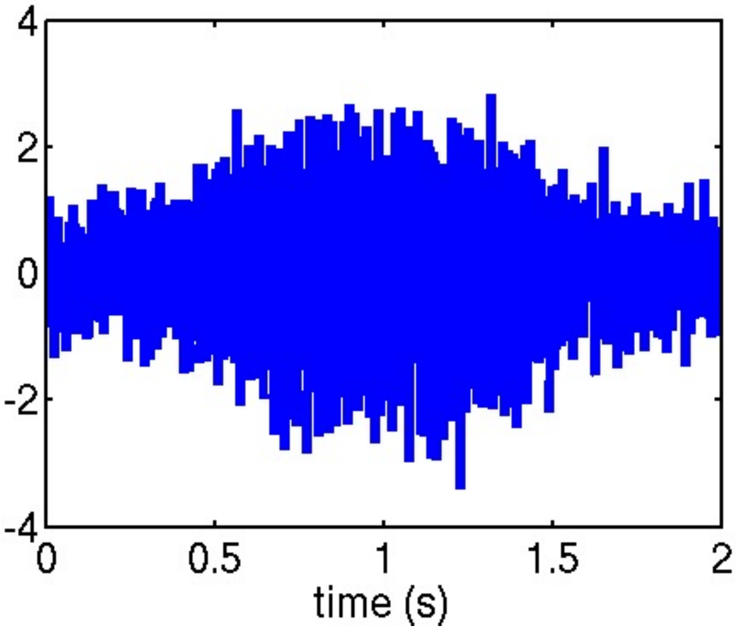
Depends on the phenomenon you want to investigate:

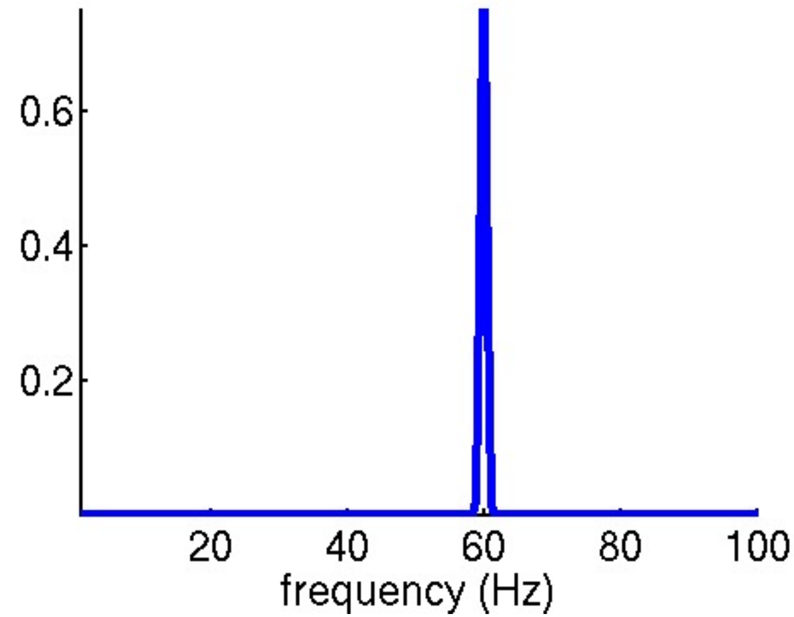
- Which time scale?
- Bandwidth?




```
cfg = [];
cfg.method      = 'mtmconvol';
cfg.foi         = [2 4 … 40];
cfg.toi         = [0:0.050:1.0];
cfg.t_ftimwin = [0.5 0.5 … 0.5];
cfg.tapsmofrq = [ 4   4   …   4 ];
           .
           .
freq = ft_freqanalysis(cfg,data);
```

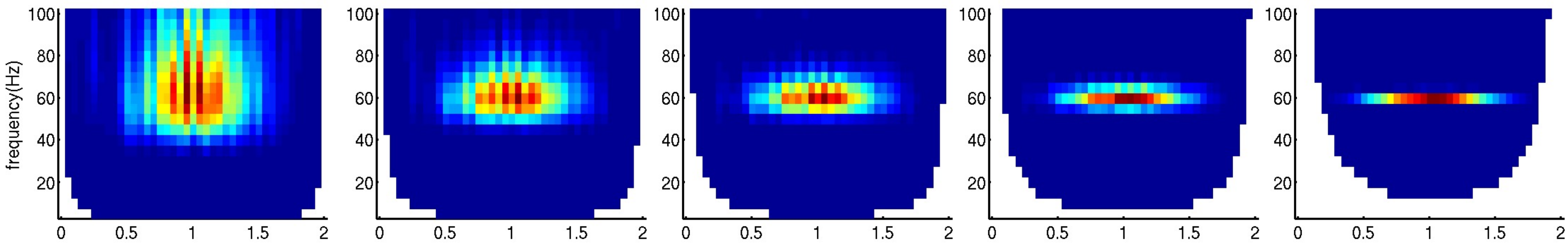
# Time versus frequency resolution




short timewindow

long timewindow



# Wavelet analysis

Popular method to calculate time-frequency representations

Is based on convolution of signal with a family of ‘wavelets’ which capture the different frequency components in the signal

Convolution ~ local correlation

# Wavelet analysis

```
cfg  = [];
cfg.method = 'wltconvol';
       .
       .
       .
freq=ft_freqanalysis(cfg, data);
```

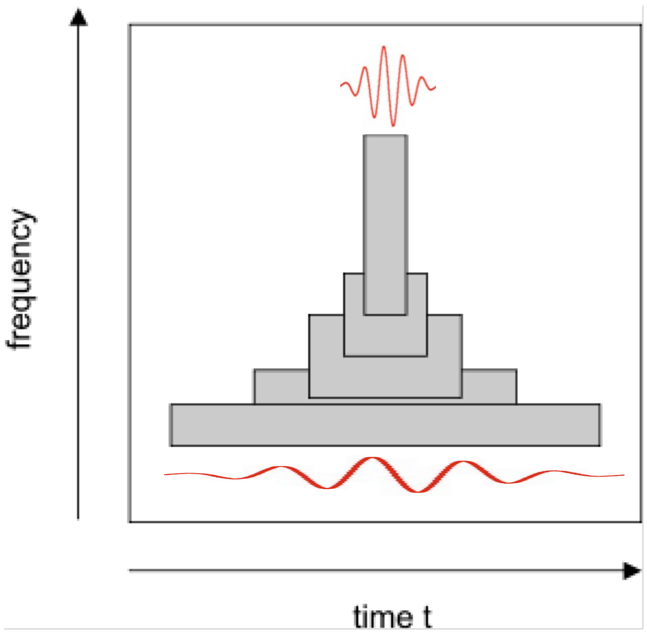
# Wavelet analysis

Wavelet width determines the time-frequency resolution

Width is a 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: going from time to frequency domain

Spectral leakage and (multi-)tapering

Time-frequency analysis

## This afternoon: hands-on

- Time-frequency analysis on real data
- Different methods
- Parameter tweaking
- Power versus baseline
- Visualization