Fieldtrip

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- Connectivity analysis using the FieldTrip toolbox

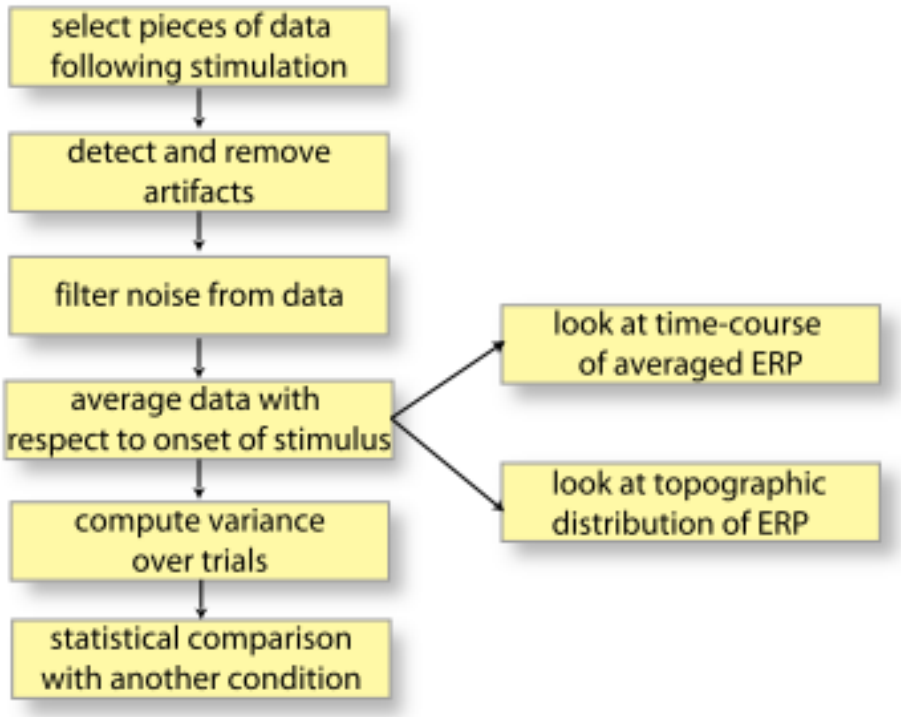
  - Overview: The Fieldtrip Toolbox is platform independent collection of matlab functions.

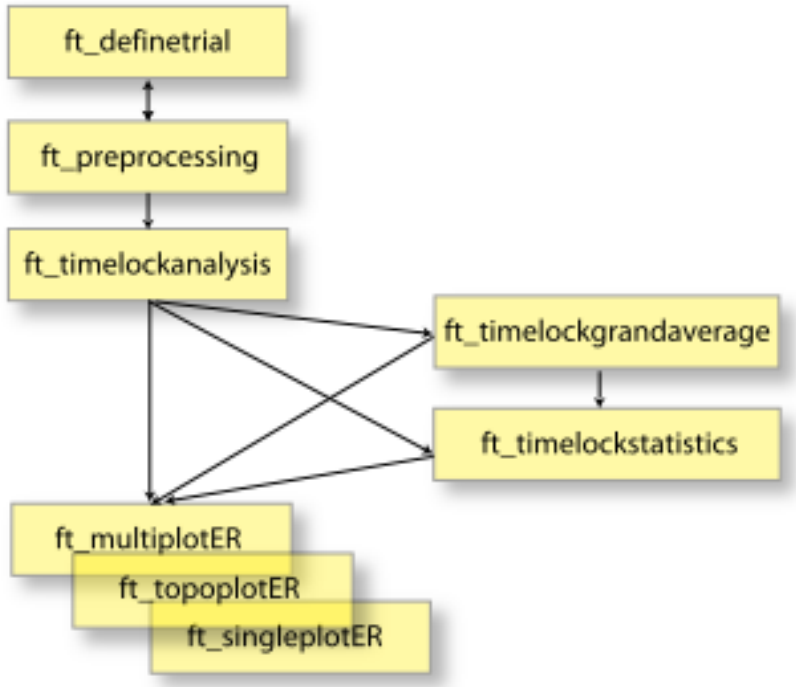
  - Tutorial (Matlab) Section:

    - Topic 1.1: Spike Analysis
    - Topic 1.2: Spike LFP Analysis
    - Topic 2.1: Time Frequency Analysis
    - Topic 2.2: Coherence Analysis
    - Topic 2.3: Connectivity Analysis

- For an analysis project high-end functions are adjusted and assembled. Example: Steps for an ERP study:

- The FieldTrip **Analysis Protocol** would have this structure:





- General Overview of High-Level Functions:

  - Functions for preprocessing, reading and coverting data (e.g. ft_preprocessing)
  - Functions for analyzing event-related fields or potentials (ERF/ERP) (e.g. ft_timelockanalysis)
  - Functions for frequency and time-frequency analysis (e.g. ft_freqanalysis)
  - Functions for source analysis (e.g. ft_sourceanalysis)
  - Functions for statistical analysis (e.g. ft_timelockstatistics)
  - Functions for plotting and displaying the data (e.g. ft_multiplotER)
  - Function for real-time acquisition and analysis (e.g. ft_realtime_average)

- External Toolboxes work together with FieldTrip and are partly integrated, e.g.:

  - FreeSurfer
  - SPM
  - Open MEG
  - Brain network Toolbox functions (Graph Theory)

Class of data	Manufacturer/file format
MEG file formats	CTF/VSM
	Neuromag/Elekta
	BTi/4D Neuroimaging
	Yokogawa/KIT
	Chieti ITAB system
EEG file formats	BrainProducts/BrainVision
	NeuroScan
	Electrical Geodesics, Inc.
	Megis software/BESA research
	Biosemi
	BCI2000
	ANT/EEProbe
	Curry
	Micromed
	Nexstim
	European data format
	Generic standard formats
Anatomical MRI formats	Dicom
	NIfTI
	Analyze
	MINC
	AFNI
Animal electrophysiology file formats	Neuralynx
	Plexon
	Tucker Davis Technology
	Cambridge Electronic Design

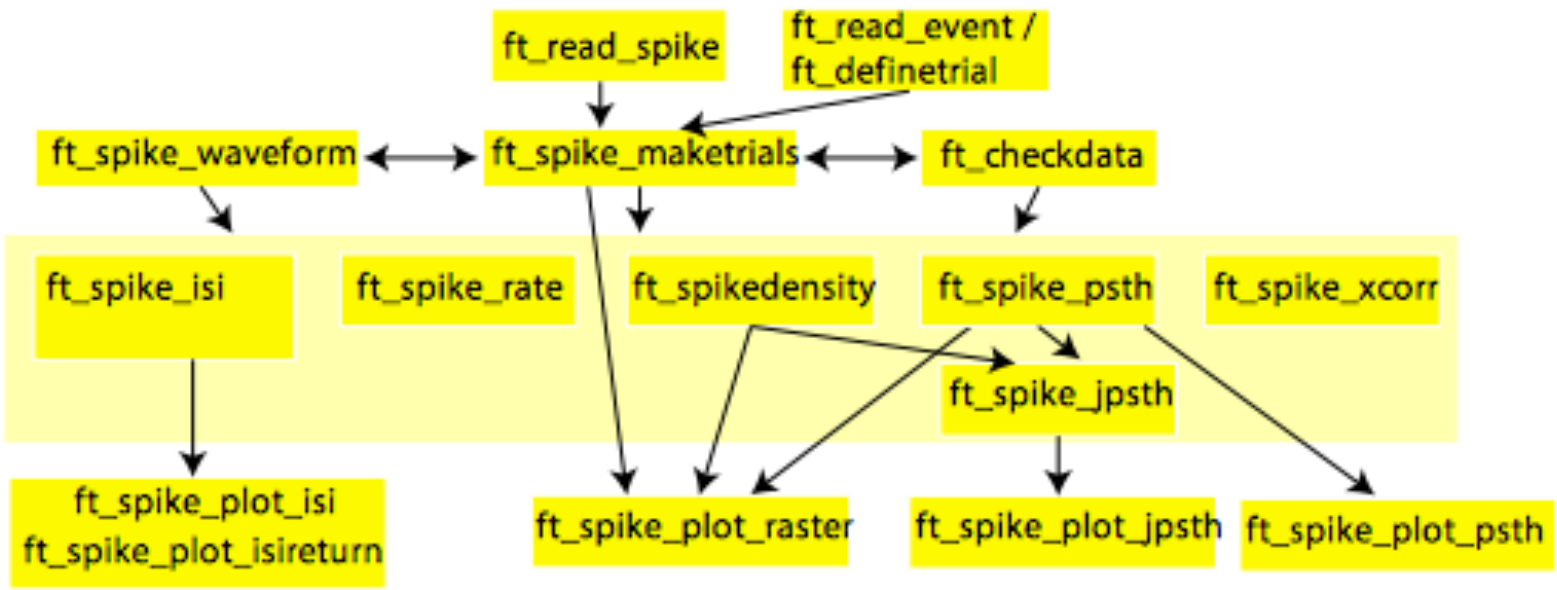
- Subselection of File formats supported by FieldTrip (A sub-selection)

- Data Representation

```
data =
      trial:  {1x100 cell}
       time:  {1x100 cell}
      label:  {275x1 cell}
        hdr:  [1x1 struct]
       grad:  [1x1 struct]
        cfg:  [1x1 struct]
>> data.time (1)
ans =
    [1x600 double]
>> data.trial (1)
ans =
    [275x600 double]
```

```
freq =
      powspctrm:  [275x10x50 double]
         dimord:  'chan_freq_time'
          label:  {275x1 cell}
           freq:  [1x10 double]
           time:  [1x50 double]
            cfg:  [1x1 struct]
```

- Example Processing Pipeline: Spike Analysis



• Overview of Tutorials - 1-

Introduction to using FieldTrip with Matlab

- Introduction

Computational aspects and scripting

- Creating an efficient analysis script
- Dealing with memory issues
- Speeding up your analysis with distributed computing

Preprocessing

- Preprocessing - Trigger based trial selection
- Preprocessing - Reading continuous data

Dealing with artifacts

- Introduction on artifacts
- Visual artifact detection
- Automatic artifact detection

Sensor-level analyses

- Overview of sensor-level analyses
- Event related fields and the planar gradient
- Preprocessing of EEG data and computing ERPs
- Time-frequency analysis using Hanning window, multitapers and wavelets

• Overview of Tutorials - 2 -

Source reconstruction

- Construct a headmodel for MEG source analysis
- Construct a headmodel for EEG source analysis
- Localizing oscillatory sources using beamformer techniques
- Localizing visual gamma and cortico-muscular coherence
- Source reconstruction of event-related fields using minimum-norm estimate
- Computation of virtual MEG channels in source-space

Connectivity analysis

- Analysis of corticomuscular coherence
- Analysis of sensor- and source-level connectivity

Statistics

- Parametric and non-parametric statistics on event related fields
- Cluster-based permutation tests on event related fields
- Cluster-based permutation tests on time-frequency data
- Multivariate analysis of MEG/EEG data

• Overview of Tutorials - 3 -

Visualizing the results of an analysis

- Plotting data at the channel and source level
- Specifying the channel layout for plotting

Analysis of spiketrains

- Preprocessing and analysis of spike-train data
- Preprocessing and analysis of spike and local field potential data

Analysis of TMS-EEG data

- Dealing with TMS-EEG datasets

- Connectivity analysis using the FieldTrip toolbox

  - Overview: The Fieldtrip Toolbox is platform independent collection of matlab functions.

  - Tutorial (Matlab) Section:

    - Topic 1.1: Spike Analysis
    - Topic 1.2: Spike LFP Analysis
    - Topic 2.1: Time Frequency Analysis
    - Topic 2.2: Coherence Analysis
    - Topic 2.3: Connectivity Analysis

Measuring and Analyzing Brain Connectivity in Electrophysiolgical Measurements
of Spike and Local Field Potential activity using **Fieldtrip**
[CosMo 2014 - Thilo Womeldorf - www.attentionlab.ca]

FieldTrip: http://fieldtrip.fcdonders.nl/
FieldTrip Download: http://github.com/fieldtrip/fieldtrip
Function Overview: http://fieldtrip.fcdonders.nl/reference
Fieldtrip Community: https://www.facebook.com/fieldtriptoolbox

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• SPIKE ANALYSIS, COMMON MEASURES

Tutorial link: http://fieldtrip.fcdonders.nl/tutorial/spike
Tutorial dataset: ftp://ftp.fcdonders.nl/pub/fieldtrip/tutorial/spike/p029_sort_final_01.nex

Content / Tutorial Objectives:
- Memory efficient representation of spike data; trial selection, spike waveform analysis, Interspike-interval distribution and return maps; raster plot / peri-stimulus time histograms (PSTH); cross-correlations; joint (j)PSTH,

Questions:
- What are the pros and cons of the two main ways to represent spike data in Fieldtrip?
- Why is it useful to analyze waveforms of spikes ?
- Which information conveys an interspike interval ?
- What is measured with a joint peristimulus time histogram (JPSTH) analysis?
- What does a shuffle predicted JPSTH control for and how does it do this?

• SPIKE - LOCAL FIELD POTENTIAL ANALYSIS

Tutorial link: http://fieldtrip.fcdonders.nl/tutorial/spikefield
Tutorial dataset: ftp://ftp.fcdonders.nl/pub/fieldtrip/tutorial/spikefield/p029_sort_final_01.nex.

Content / Tutorial Objectives:
- Representing point processes (spikes) and continuous data (LFP), Spike-Triggered LFP Averages; Circular statistics on spike-phases; Unbiased and refractoriness corrected Pairwise-Phase Consistency (PPC), Phase Locking Values (PLV)

Questions:
- What additional information is provided by the PPC compared to the Spike Triggered (LFP) Average ?
- What is the advantage of the PPC over the PLV in spike-field synchronization analysis

• TIME FREQUENCY ANALYSIS

Tutorial link: http://fieldtrip.fcdonders.nl/tutorial/timefrequencyanalysis

Tutorial dataset: ftp://ftp.fcdonders.nl/pub/fieldtrip/tutorial/Subject01.zip.

Content / Tutorial Objectives:
- Time-frequency Analysis of Power; Similarity and differences of frequency analysis methods (Hanning, multitaper, Wavelet); Multitaper time frequency analysis; Effects of analysis time windows on frequency resolution; Effects of taper smoothing width on time frequency results.

Questions:
- What are differences between multitaper- and wavelet- methods ?
- Why is it not recommended to use multitapers for low (<20 Hz) frequencies ?
- Which criteria do you use to determine the time window width for a time-freq analysis of experimental data?
- Which criteria are you applying to choose the taper smoothing frequency ?

• COHERENCE ANALYSIS

Tutorial link: http://fieldtrip.fcdonders.nl/tutorial/coherence
Tutorial dataset: ftp://ftp.fcdonders.nl/pub/fieldtrip/tutorial/coherence/data.mat
or: ftp://ftp.fcdonders.nl/pub/fieldtrip/tutorial/SubjectCMC.zip
ftp://ftp.fcdonders.nl/pub/fieldtrip/tutorial/coherence/trialfun_left.m

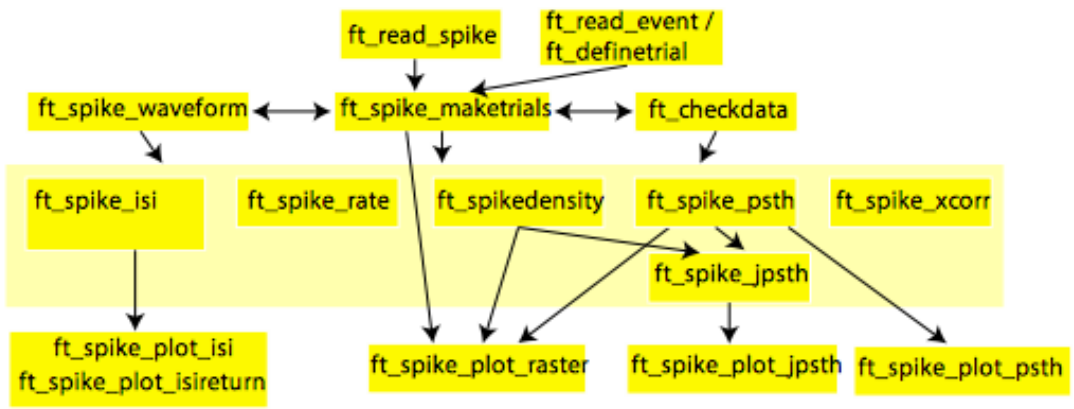
Content / Tutorial Objectives:
- EMG - MEG coherence analysis; Filtering and preprocessing of signals; Changing frequency resolutions; Analysis of Power-spectra and cross-spectral densities; Influence of different taper smoothing of EMG and/or MEG channels on EMG-MEG coherence; Influence of number of trials on coherence estimates.

Questions:
- What is cortico-muscular coherence ?
- How do results change with low versus high taper smoothing of the multitaper fourier analysis preceding coherence ?
- How do the number of trials available for analysis influence the coherence results?

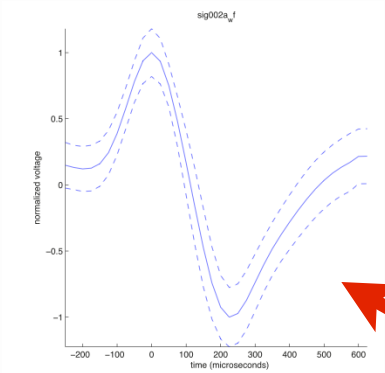
• Tutorial Content Overview - Spike Analysis

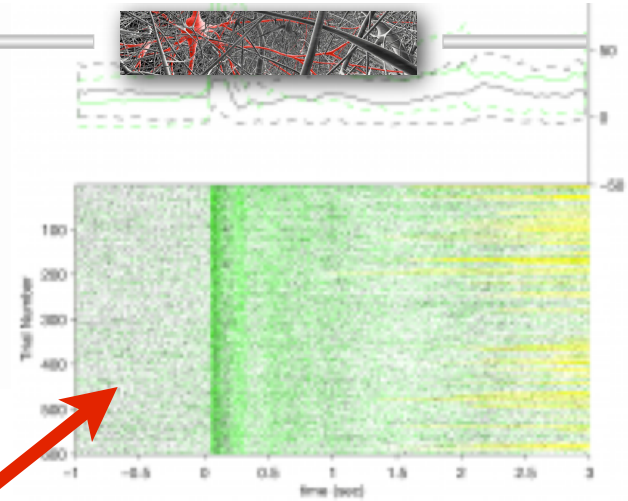
Preprocessing and analysis of spike-train data

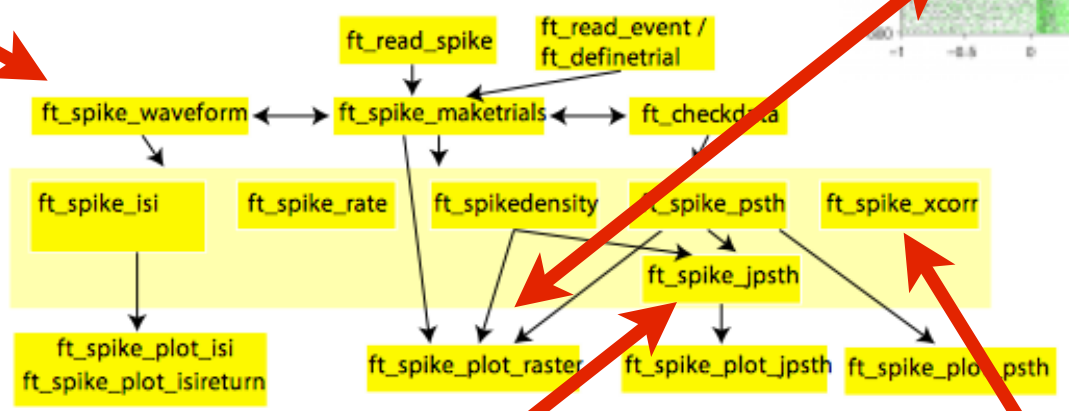
- Introduction
- Background
- Procedure
  - Reading in spike data
  - Computing average waveforms
  - Adding trigger event information to spike structure
  - Converting spike structure to continuous raw format and back
  - Characterizing inter-spike-interval (ISI) distributions
  - Computing spike densities and peri-stimulus time histograms (PSTHs)
  - Computing average firing rates and noise correlations
  - Computing cross-correlations between spike trains
  - The joint peri stimulus time histogram
- Summary

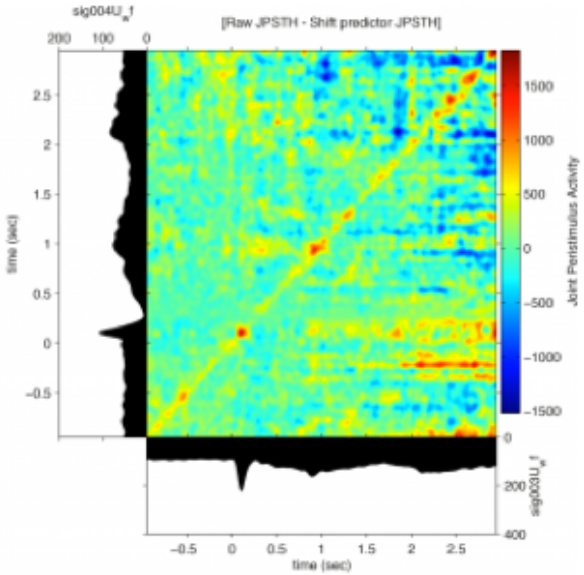


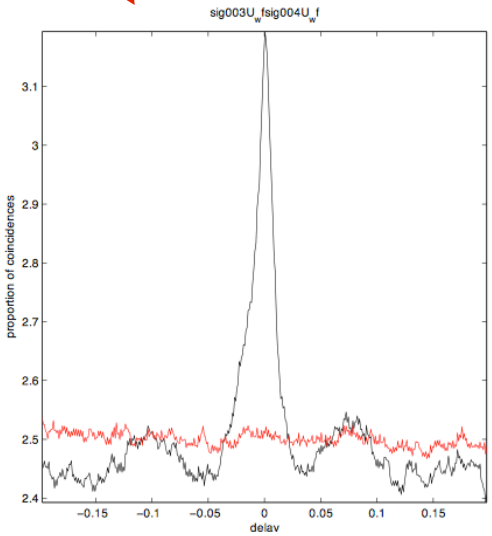
• Spike Analysis







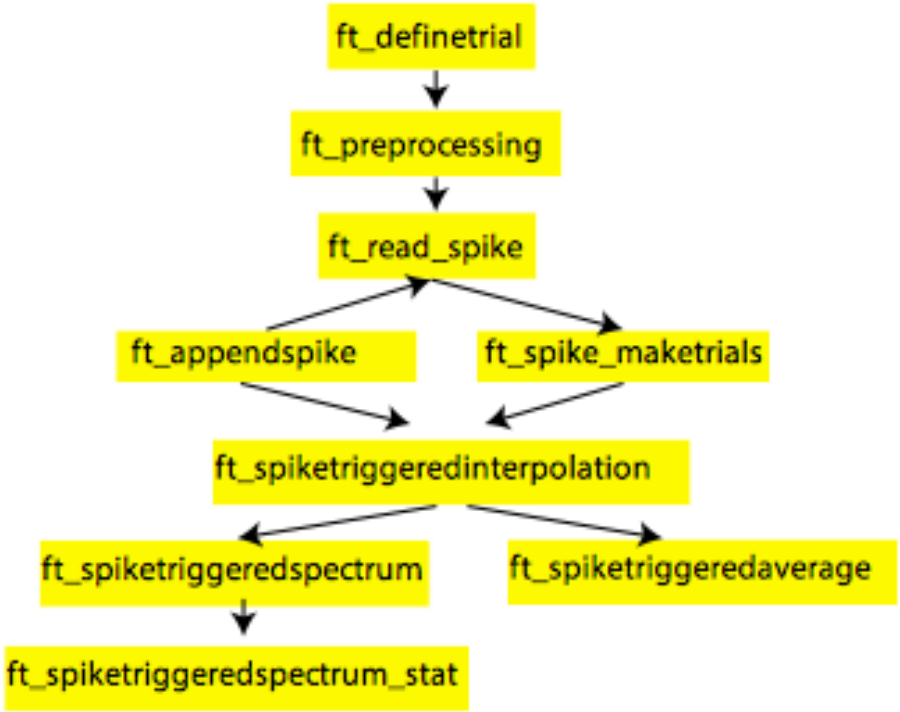




• Tutorial Content Overview - Spike LFP Analysis

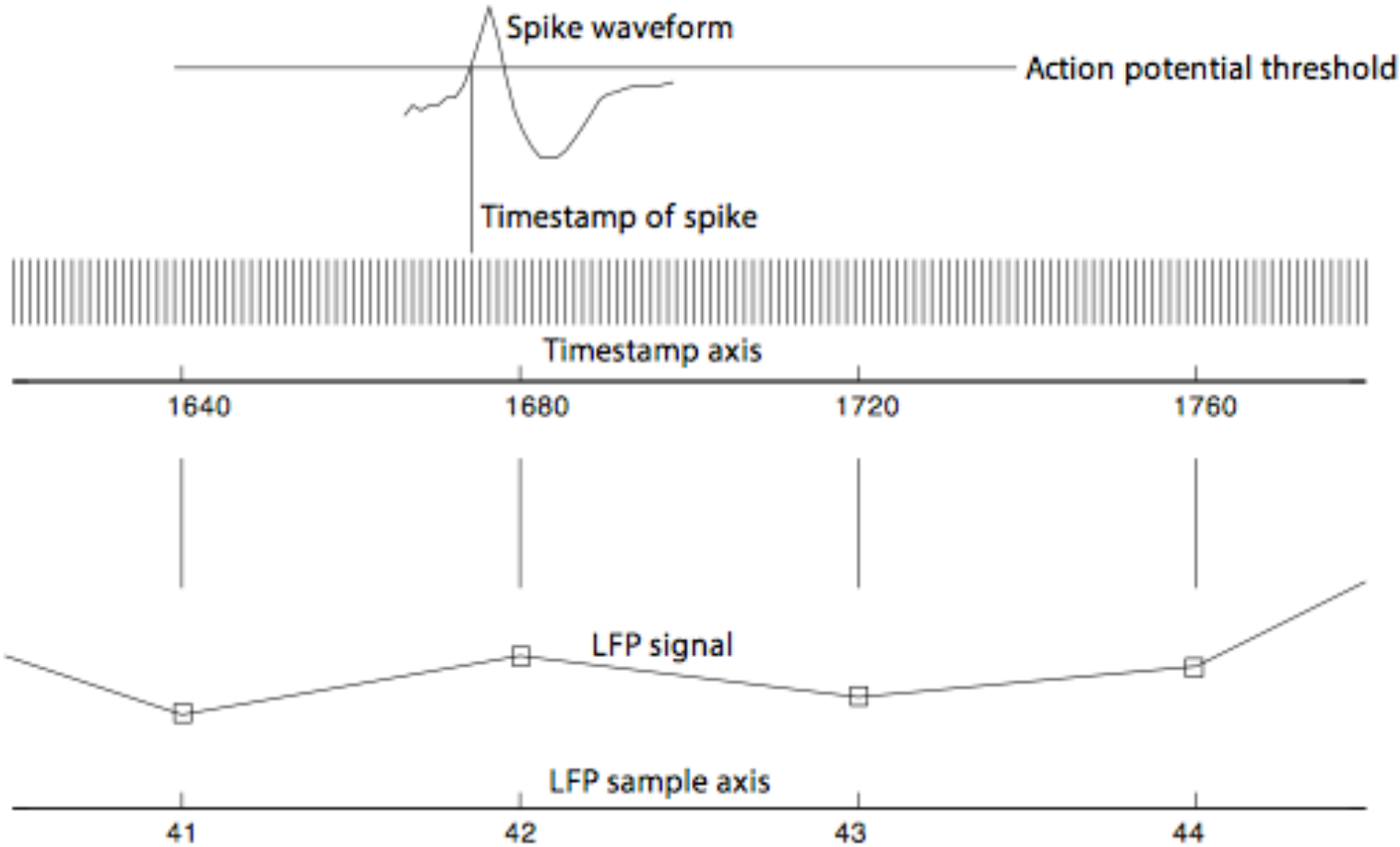
Preprocessing and analysis of spike and local field potential data

- Introduction
- Background
- Procedure
  - Preprocessing
  - Analyzing spikes and LFPs reco from the same electrode
  - Computing the spike triggered average LFP
  - Computing the phases of spike relative to the ongoing LFP
  - Computing statistics on the ou from ft_spiketriggeredspectrur
- Summary



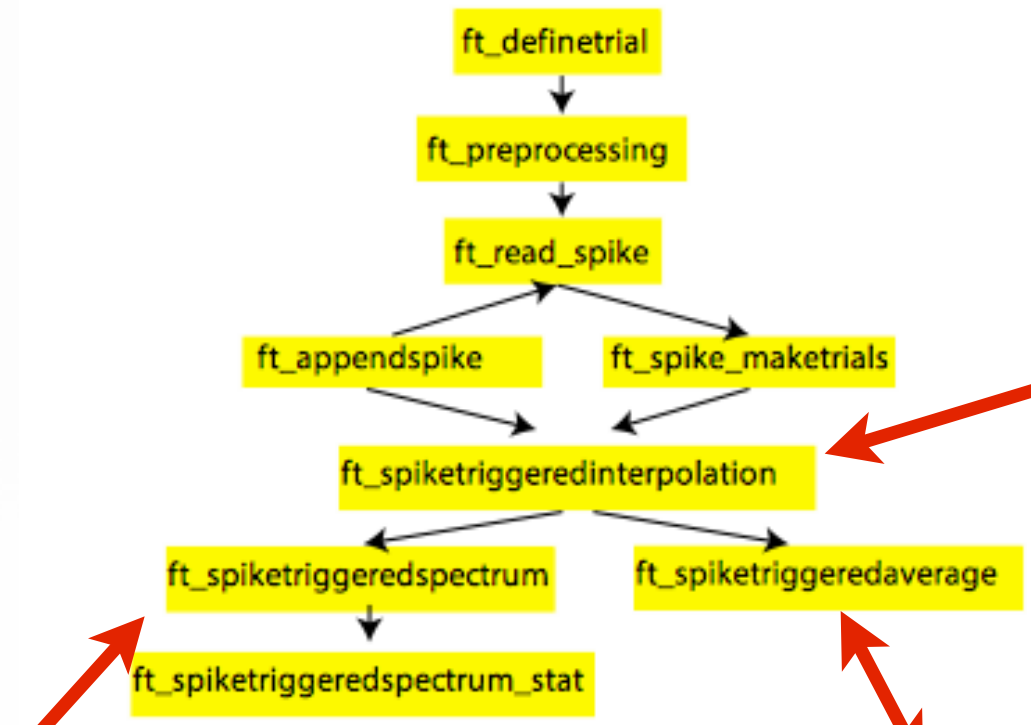
- Spike LFP Analysis

Spike Duration ~ 1.2 ms

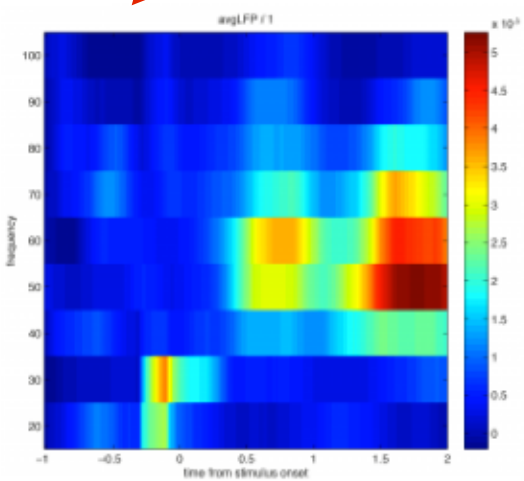


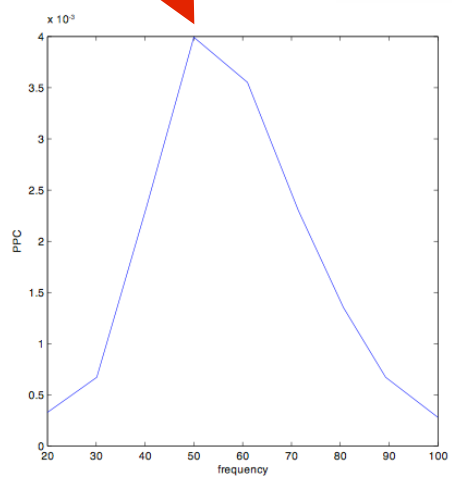
LFP Content (< 300 Hz, >3ms)

- Spike LFP Analysis



For same channel data, prevent leakage of Actio potential to LFP





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Time-frequency analysis using Hanning window, multitapers and wavelets

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- Time-frequency analysis I.
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- Visualization
- Time-frequency analysis II.
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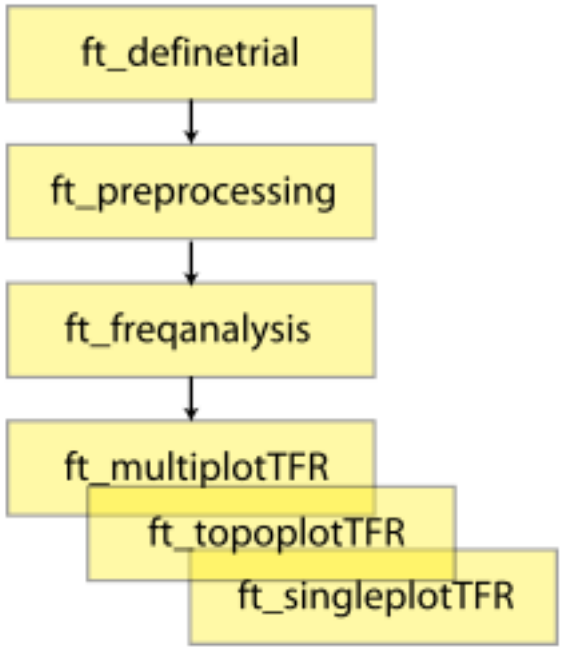
- Time-frequency analysis IV.
  - Morlet wavelets
- Summary and suggested further reading



- Topic 2.2: Coherence Analysis

Fieldtrip - Coherence Analysis

http://fieldtrip.fcdonders.nl/tutorial/coherence

Analysis of corticomuscular coherence

- Introduction
- Background
- Procedure
- Preprocessing
- Computing the coherence
- Displaying the coherence
  - Exercise 2
  - Exercise 3
  - Exercise 4
  - Exercise 5
- Summary and further reading
- Appendix 1: Localisation of neuronal sources coherent with the EMG using beamformers
- Appendix 2: trialfun_left

- Topic 2.2: Coherence Analysis

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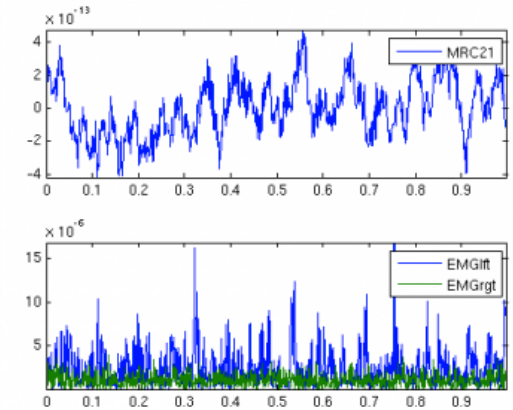

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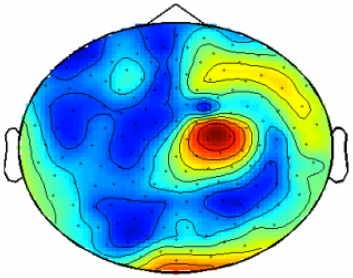

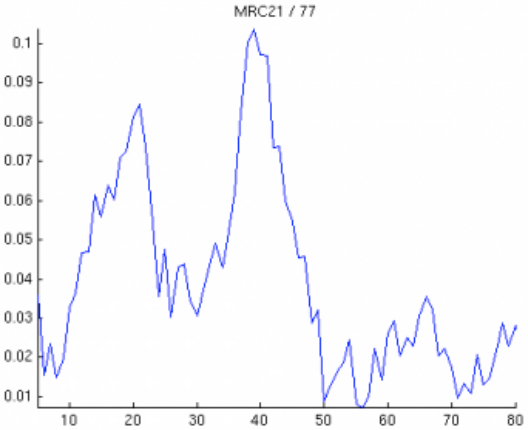

- Connectivity analysis using the FieldTrip toolbox

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- Calculating time-frequency representations of power is done using a sliding time window. This can be done with fixed time windows (left) or with variable sized windows (right).

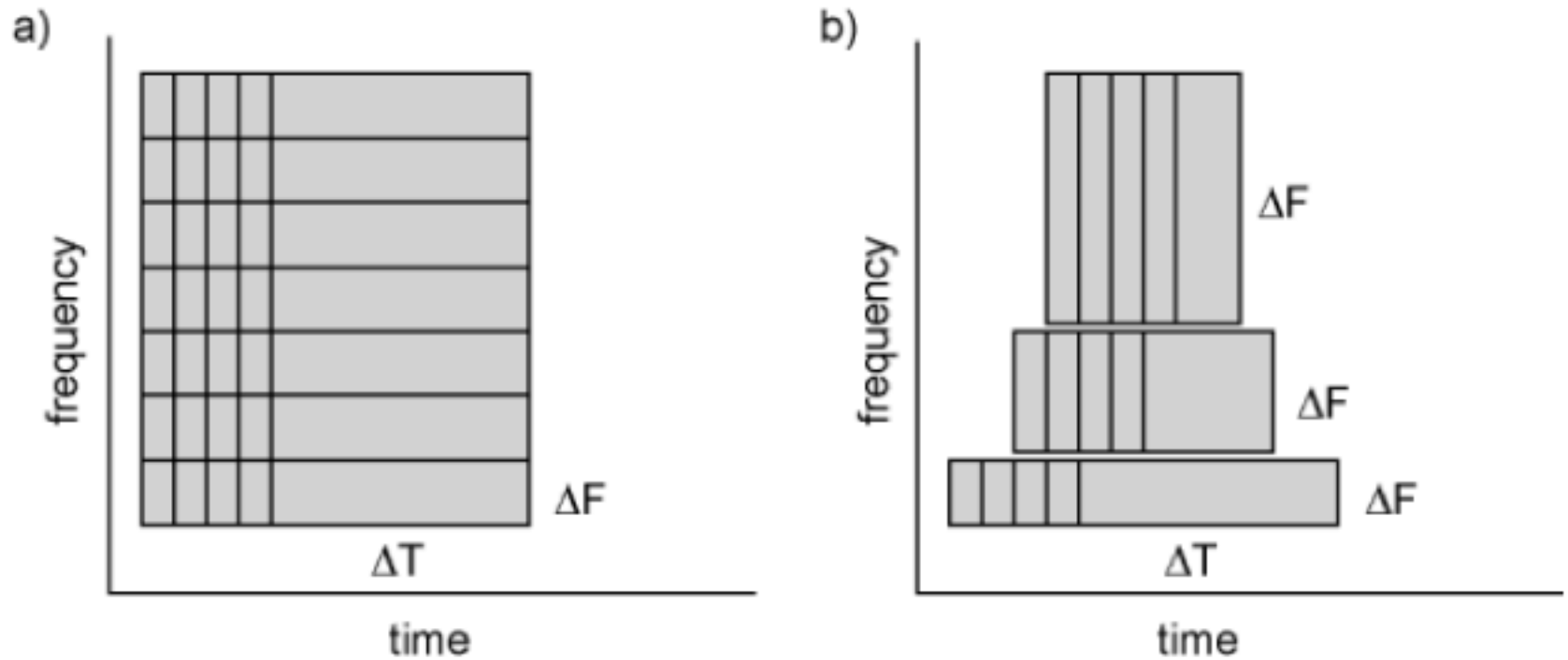


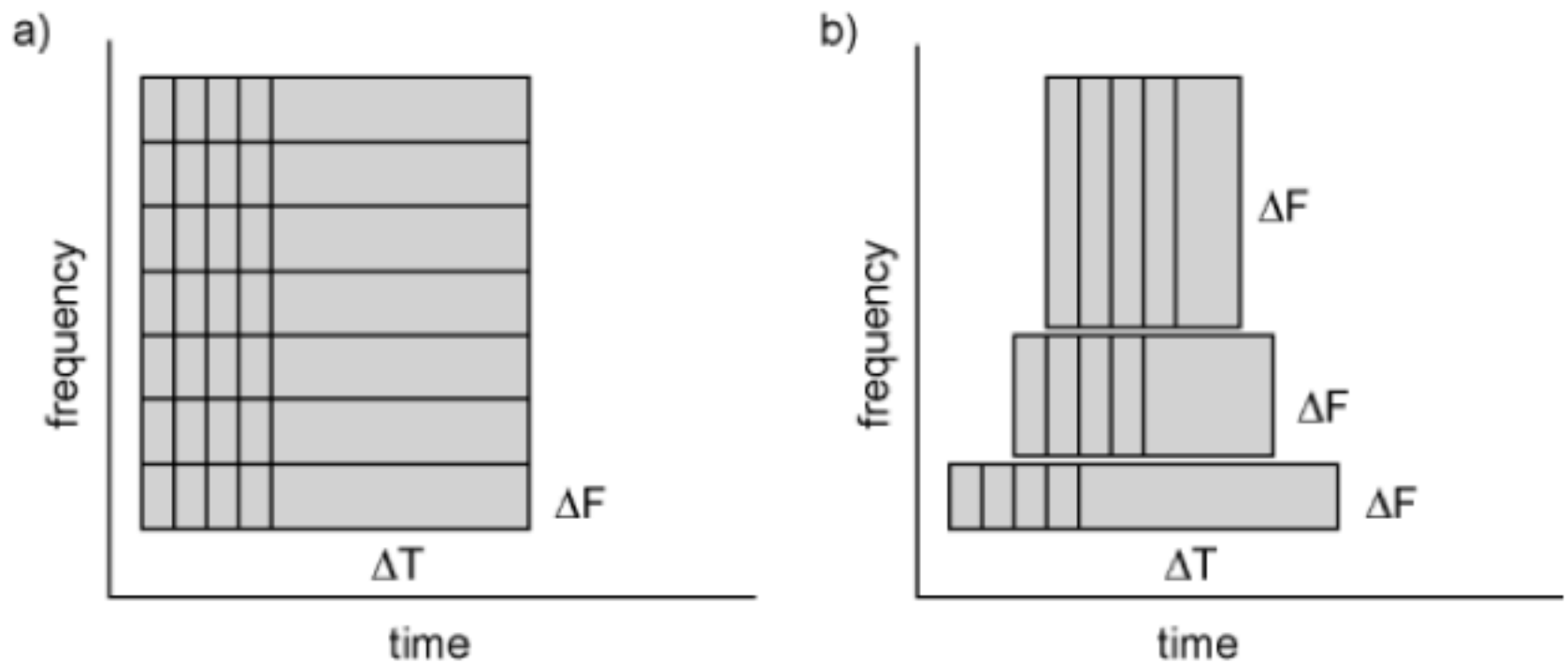
Figure 1; Time and frequency smoothing. (a) For a fixed length time window the time and frequency smoothing remains fixed. (b) For time windows that decrease with frequency, the temporal smoothing decreases and the frequency smoothing increases.

- The time window limits the Frequency Resolution

Frequency Resolution: = 1 / time window (sec.)

2 Hz = 1 / **0.5 sec.**

5 Hz = 1 / **0.2 sec.**



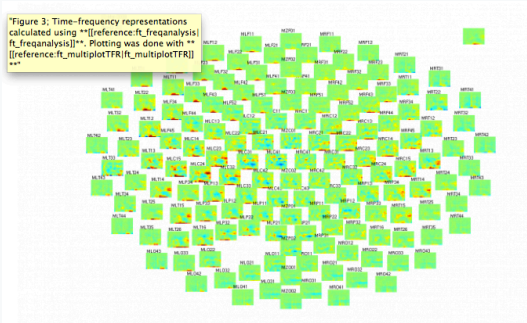
```
load dataFIC
```

```
cfg               = [];
cfg.output        = 'pow';
cfg.channel       = 'MEG';
cfg.method        = 'mtmconvol';
cfg.taper         = 'hanning';
cfg.foi           = 2:2:30;                          % analysis 2 to 30 Hz in steps of 2 Hz
cfg.t_ftimwin     = ones(length(cfg.foi),1).*0.5;    % length of time window = 0.5 sec
cfg.toi           = -0.5:0.05:1.5;                   % time window "slides" from -0.5 to 1.5 sec
in steps of 0.05 sec (50 ms)
TFRhann = ft_freqanalysis(cfg, dataFIC);
```

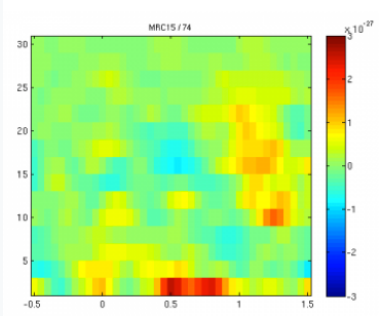
```
TFRhann =

        label: {149x1 cell}                 % Channel names
       dimord: 'chan_freq_time'             % Dimensions contained in powspctrm, channels X
frequencies X time
         freq: [2 4 6 8 10 12 14 16 18 20 22 24 26 28 30]  % Array of frequencies of interest
(the elements of freq may be different from your cfg.foi input depending on your trial length)
         time: [1x41 double]                 % Array of time points considered
    powspctrm: [149x15x41 double]            % 3-D matrix containing the power values
         grad: [1x1 struct]                  % Gradiometer positions etc
          cfg: [1x1 struct]                  % Settings used in computing this frequency
decomposition
```

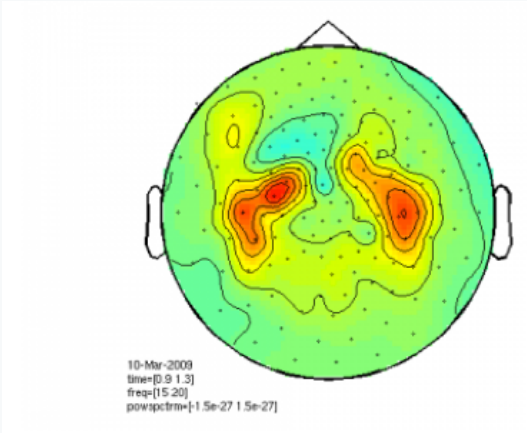
```
cfg = [];
cfg.baseline     = [-0.5 -0.1];
cfg.baselinetype = 'absolute';
cfg.zlim         = [-3e-27 3e-27];
cfg.showlabels   = 'yes';
cfg.layout       = 'CTF151.lay';
figure
ft_multiplotTFR(cfg, TFRhann);
```




```
cfg = [];
cfg.baseline     = [-0.5 -0.1];
cfg.baselinetype = 'absolute';
cfg.maskstyle    = 'saturation';
cfg.zlim         = [-3e-27 3e-27];
cfg.channel      = 'MRC15';
figure
ft_singleplotTFR(cfg, TFRhann);
```




```
cfg = [];
cfg.baseline     = [-0.5 -0.1];
cfg.baselinetype = 'absolute';
cfg.xlim         = [0.9 1.3];
cfg.zlim         = [-1.5e-27 1.5e-27];
cfg.ylim         = [15 20];
cfg.marker       = 'on';
figure
ft_topoplotTFR(cfg, TFRhann);
```



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- Procedure
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- Time-frequency analysis I.
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- Visualization
- Time-frequency analysis II.
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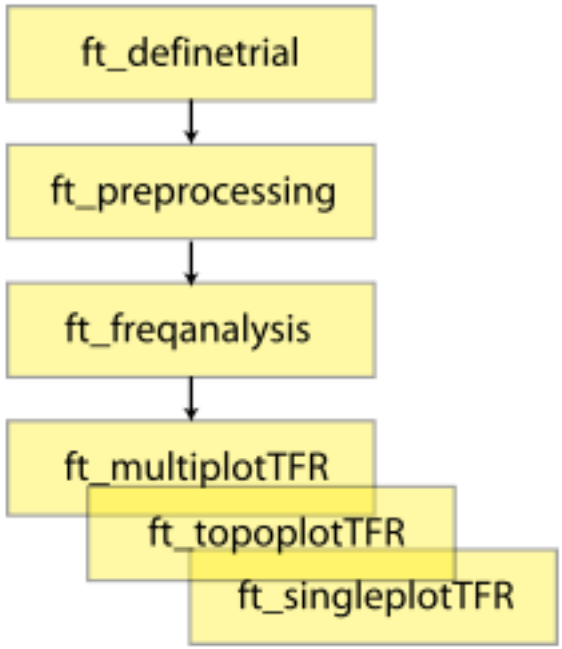
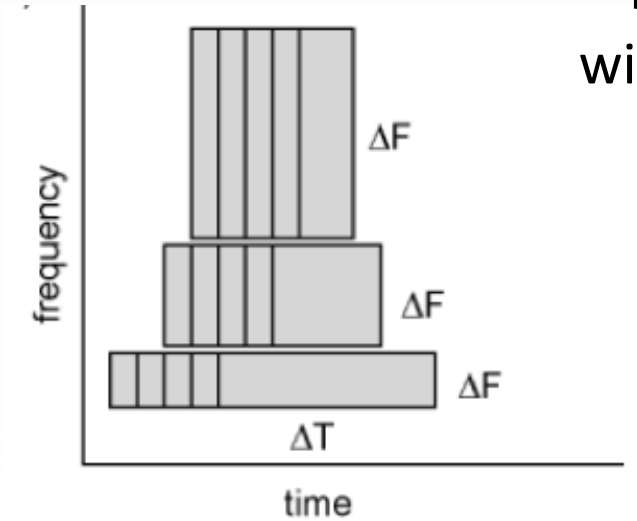
  - Multitapers
- Time-frequency analysis IV.
  - Morlet wavelets
- Summary and suggested further reading



- Effects of variable Time Windows



- If you want 7 cycles per window, the time window is

1000 ms for 7 Hz (1/7 x 7 cycles)

700 ms for 10 Hz (1/10 x 7 cycles)

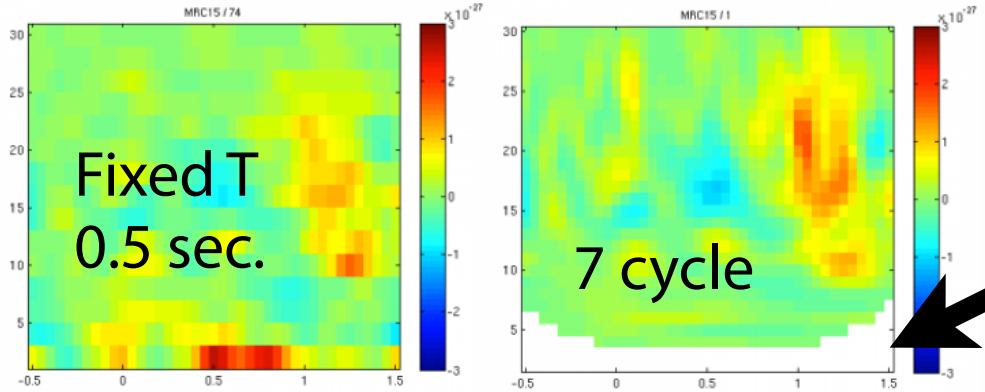
350 ms for 20 Hz (1/20 x 7 cycles)

140 ms for 50 Hz (1/50 x 7 cycles)

```
cfg                 = [];
cfg.output          = 'pow';
cfg.channel         = 'MRC15';
cfg.method          = 'mtmconvol';
cfg.taper           = 'hanning';
cfg.foi             = 2:1:30;
cfg.t_ftimwin       = 7./cfg.foi;  % 7 cycles per time window
cfg.toi             = -0.5:0.05:1.5;
TFRhann7 = ft_freqanalysis(cfg, dataFIC);
```

7 cycle time window

- Effects of variable Time Windows



at 2 Hz the window is too long for the 3sec cutted segment:
3.5 sec (1/2Hz) * 7 cycles = 3.5 sec)

```
cfg                 = [];
cfg.output          = 'pow';
cfg.channel         = 'MRC15';
cfg.method          = 'mtmconvol';
cfg.taper           = 'hanning';
cfg.foi             = 2:1:30;
cfg.t_ftimwin       = 7./cfg.foi;  % 7 cycles per time window
cfg.toi             = -0.5:0.05:1.5;
TFRhann7 = ft_freqanalysis(cfg, dataFIC);
```

7 cycle time window

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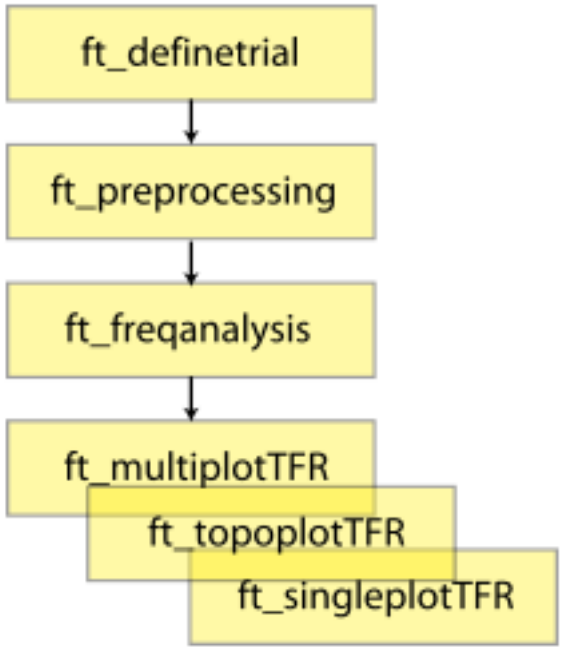
  - Morlet wavelets
- Summary and suggested further reading



- Multi-tapering

Number of Tapers (K) = 2 * Time Window (sec.) * Frequency (Hz) - 1

3 = 2*(0.5sec)*4Hz-1

3 = 2*(0.25sec)*8Hz-1

5 = 2*(0.25sec)*12Hz-1

7 = 2*(0.25sec)*16Hz-1

```
cfg = [];
cfg.output      = 'pow';
cfg.channel     = 'MEG';
cfg.method      = 'mtmconvol';
cfg.foi         = 1:2:30;
cfg.t_ftimwin   = 5./cfg.foi;
cfg.tapsmofrq   = 0.4 *cfg.foi;
cfg.toi         = -0.5:0.05:1.5;
cfg.pad         = 'maxperlen';
TFRmult = ft_freqanalysis(cfg, dataFIC);
```

The width of the frequency smoothing increases with frequency

- Topic 2.2: Coherence Analysis

Fieldtrip - Brain Connectivity Analysis

http://fieldtrip.fcdonders.nl/tutorial/coherence

- Topic 2.2: Connectivity Analysis

Fieldtrip - Brain Connectivity Analysis

http://fieldtrip.fcdonders.nl/tutorial/connectivity

Objectives: Understand that the computation of connectivity measures might be easy, but that the interpretation of the outcomes of those measures in terms of brain networks and activity remains challenging and should be exercised with caution.

Part 1: Simulate some data and use these data to compute various connectivity metrics.

Part 2: Evaluate the effect of common pick of noise up (between channels) on the consequent estimates of connectivity. Simulated data with common pick-up and different noise levels. In this part we are going to simulate some data consisting of an instantaneous mixture of 3 'sources', creating a situation of common pick up.

Fieldtrip - Brain Connectivity Analysis

http://fieldtrip.fcdonders.nl/tutorial/connectivity

Analysis of sensor- and source-level connectivity

- Introduction
- Background
- Procedure
- Simulated data with directed connections
- Connectivity between MEG virtual channel and EMG
  - Compute the spatial filter for the region of interest
  - Extract the virtual channel time-series
  - Project along the strongest dipole direction
  - Combine the virtual channel with the EMG
  - Compute the connectivity
- Summary and further reading

- main exploratory exercise

- you may try on your own

Part 1: Simulate some data and use these data to compute various connectivity metrics.

ft_connectivitysimulation	prepare data
ft_freqanalysis ft_mvaranalysis	estimating the multivariate autoregressive model and the spectral transfer function, and the cross-spectral density matrix
ft_connectivityanalysis ft_connectivityplot	compute and inspect various measures of connectivity