Brain Rhythms and Cognition

University of Amsterdam, BA Linguistics, Neurolinguistics course
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Lecture outline

First hour

1. *Reminder:* How are the signals generated in the brain
2. *Reminder:* ERPs
3. Analyzing those signals with the Fieldtrip toolbox in Matlab

Second hour

1. Fundamentals of neuronal oscillations and synchrony
2. Time-frequency representations (induced activity)
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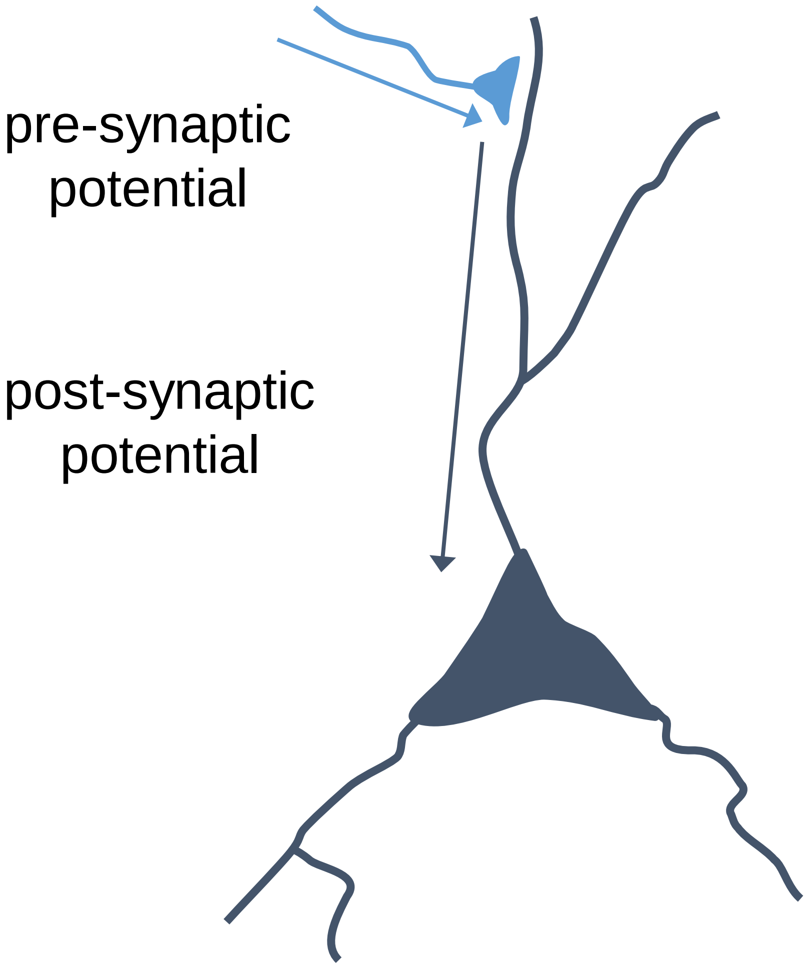
Electrical activity measured at the scalp is generated by PSPs

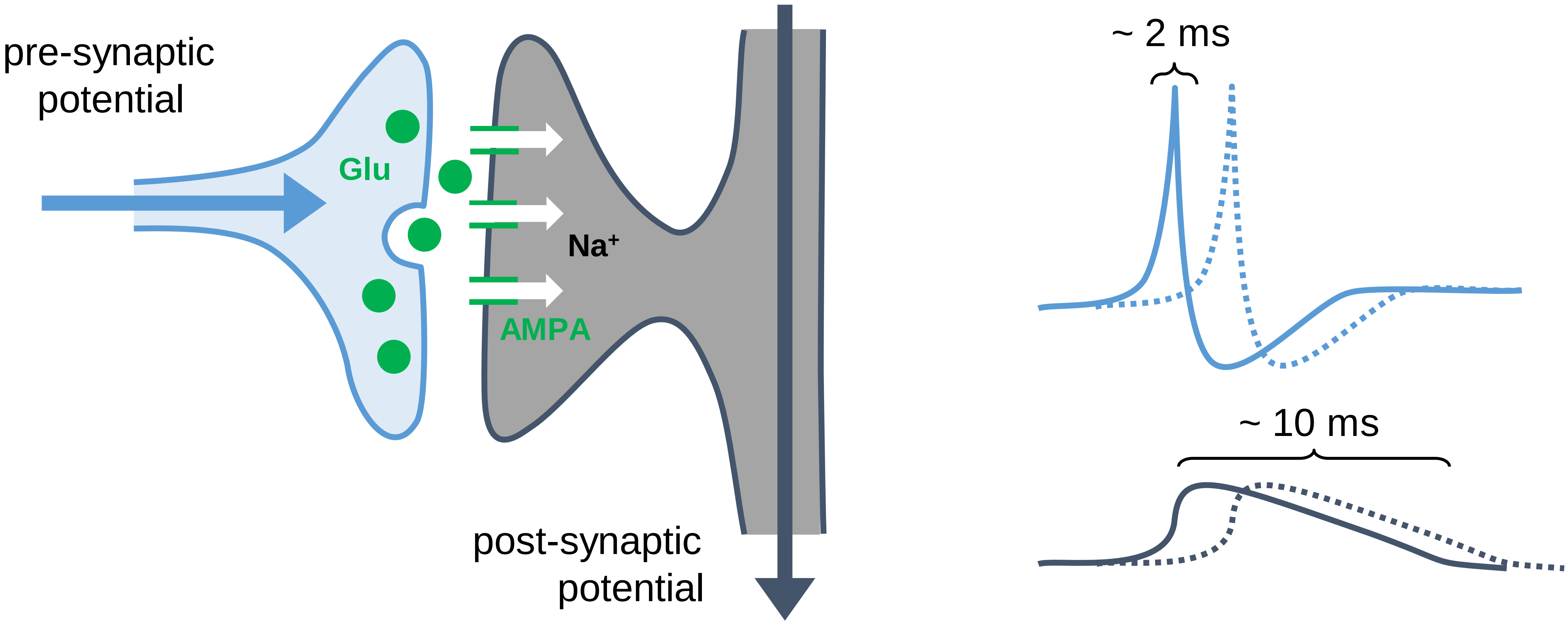


When a neuron receives input from another neuron, this causes a **post-synaptic potential (PSP)**

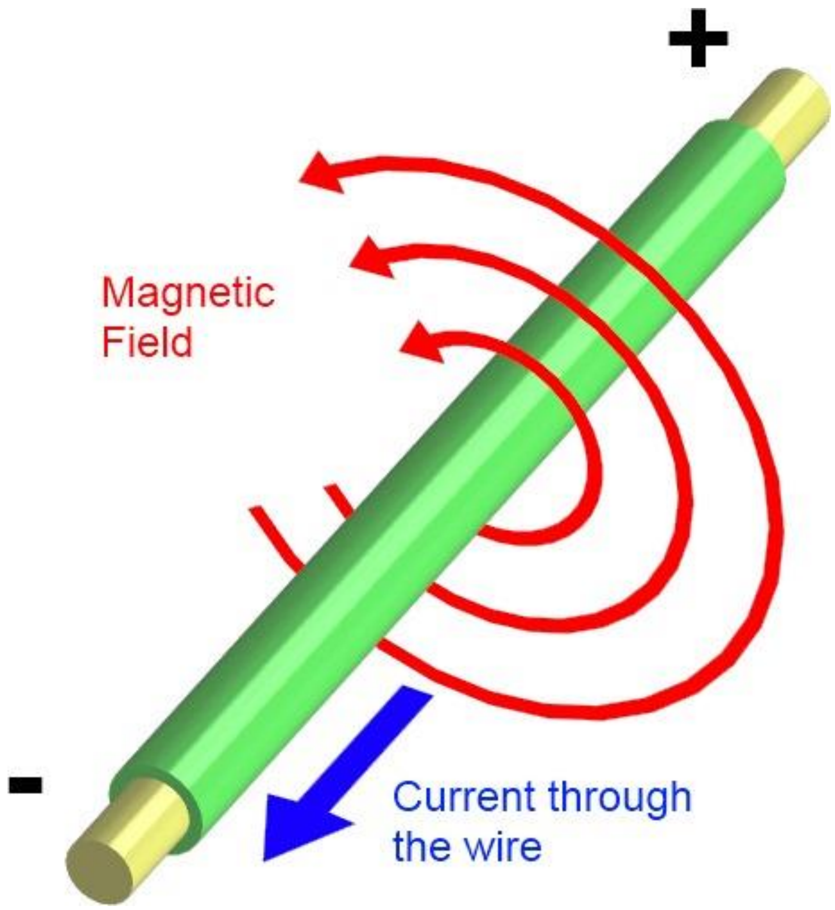
With **EEG**, we measure **electrical activity at the scalp**, which arises from PSPs in pyramidal neurons

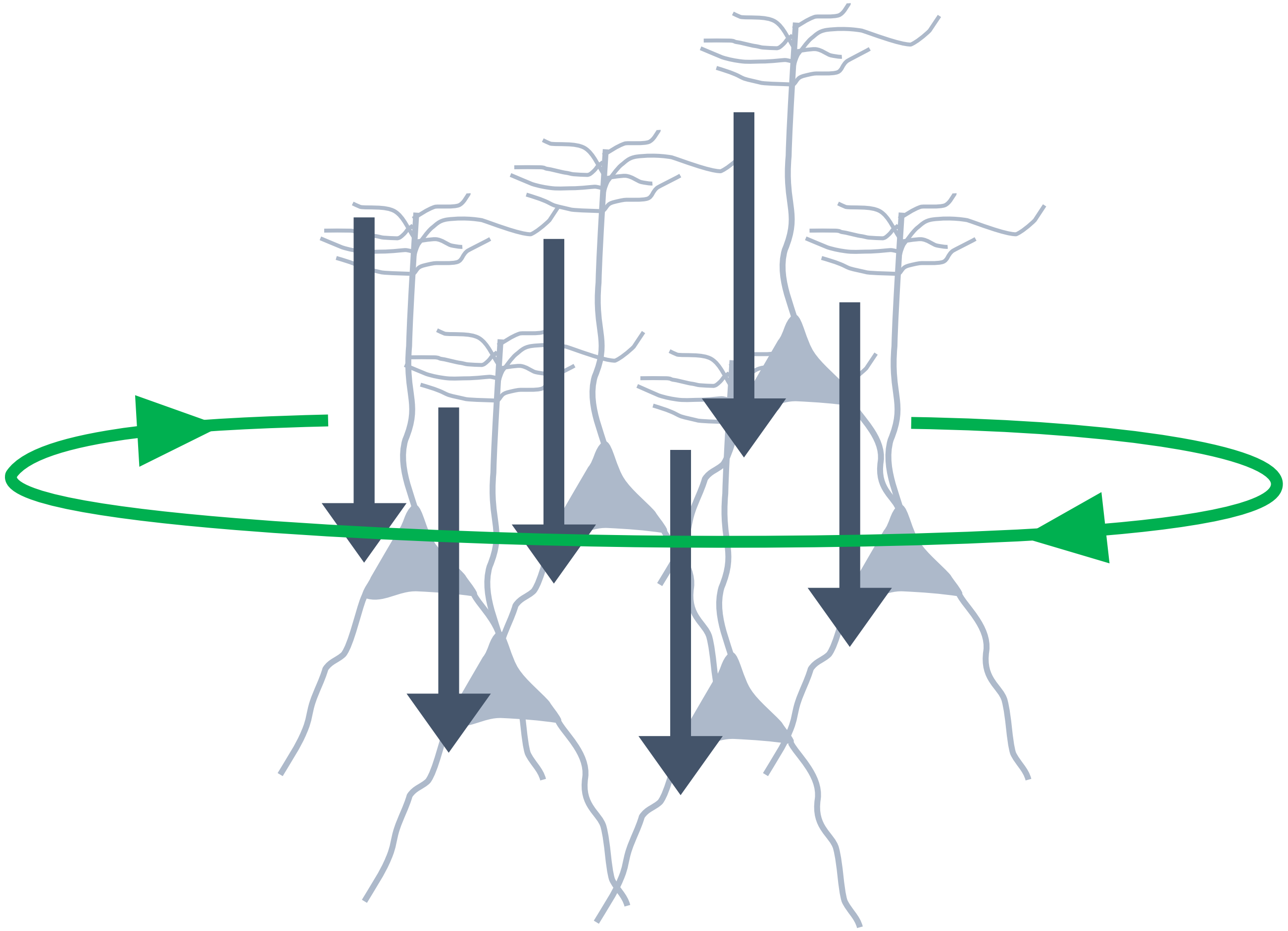
Usually, we study neuronal activity following the presentation of a stimulus or following a cognitive event

A PSP is a change in the membrane potential in micro-volts

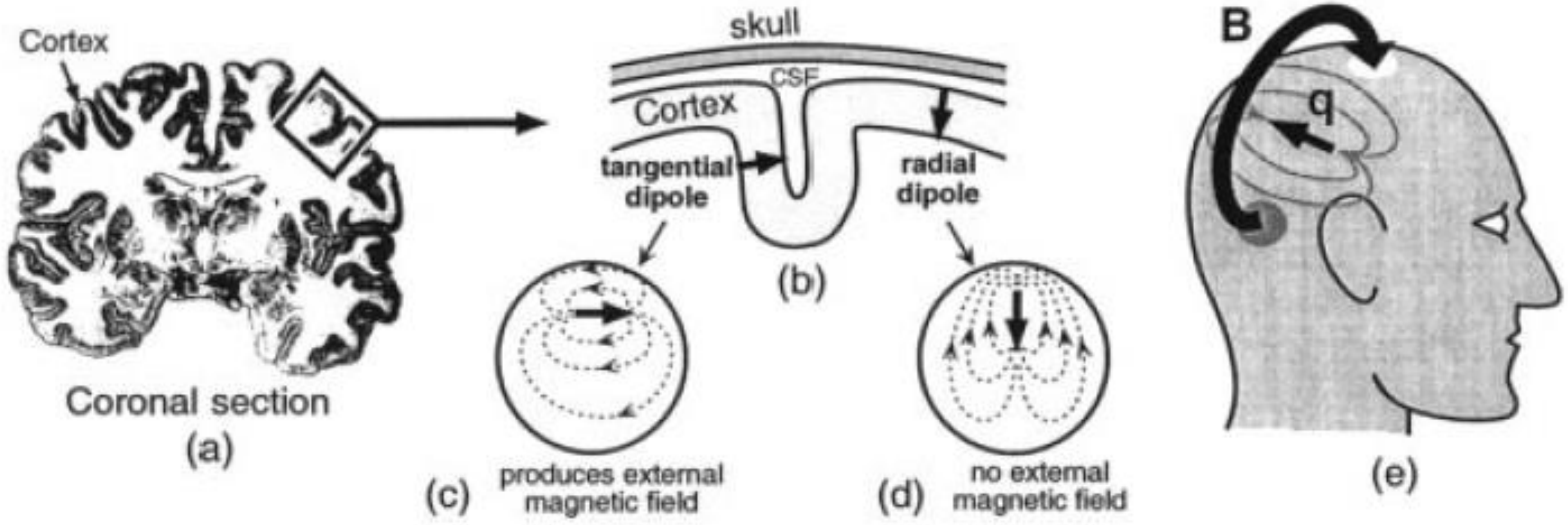


Electric currents generate a magnetic field





With MEG, we record magnetic fields



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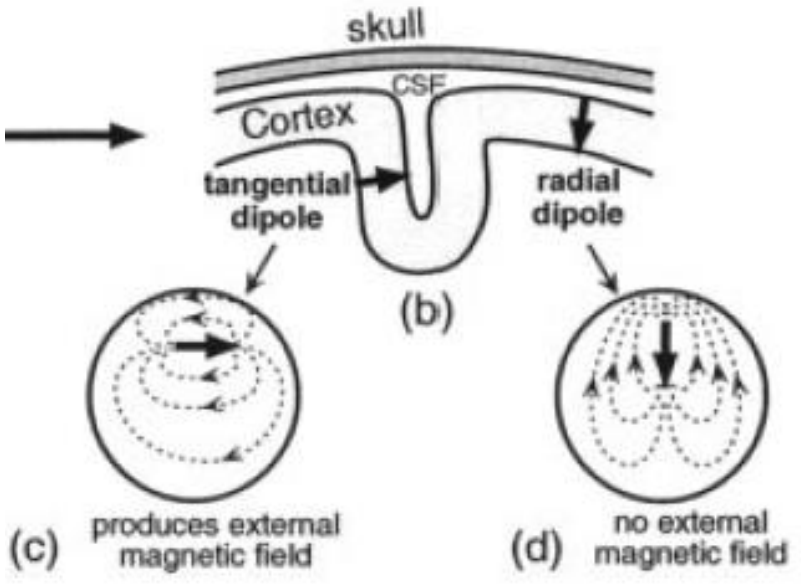

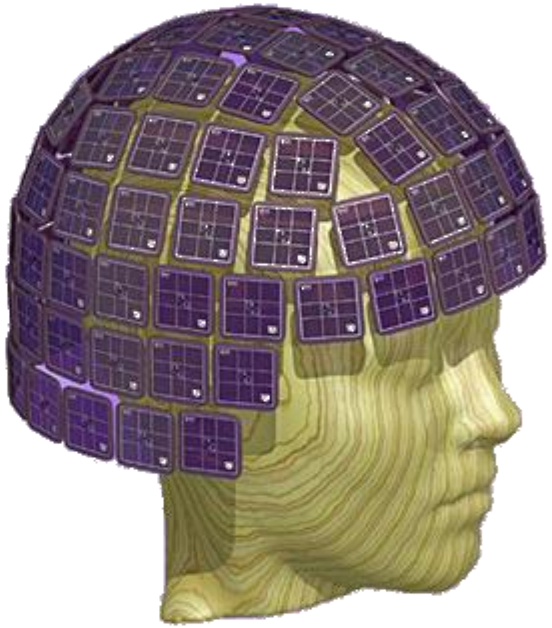

Which has a better spatial resolution: EEG or MEG? Why?

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Event-related potentials (ERPs)

Evoked activity:

The brain *signal* of interest is assumed to be constant over all trials

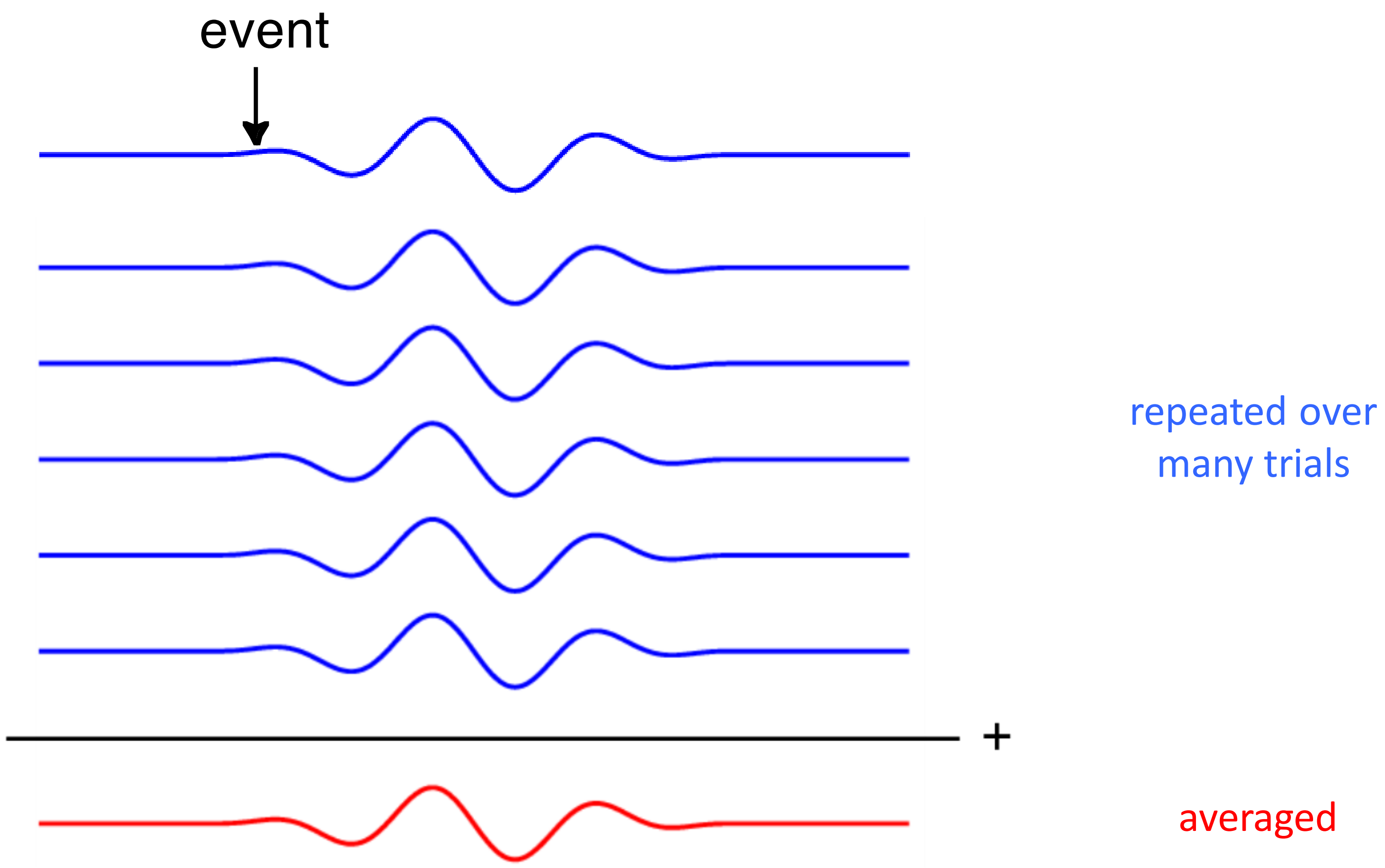
- *Semantic “violation” → N400*
- *Presentation of visual stimulus → P1*

The *noise* is independent over trials

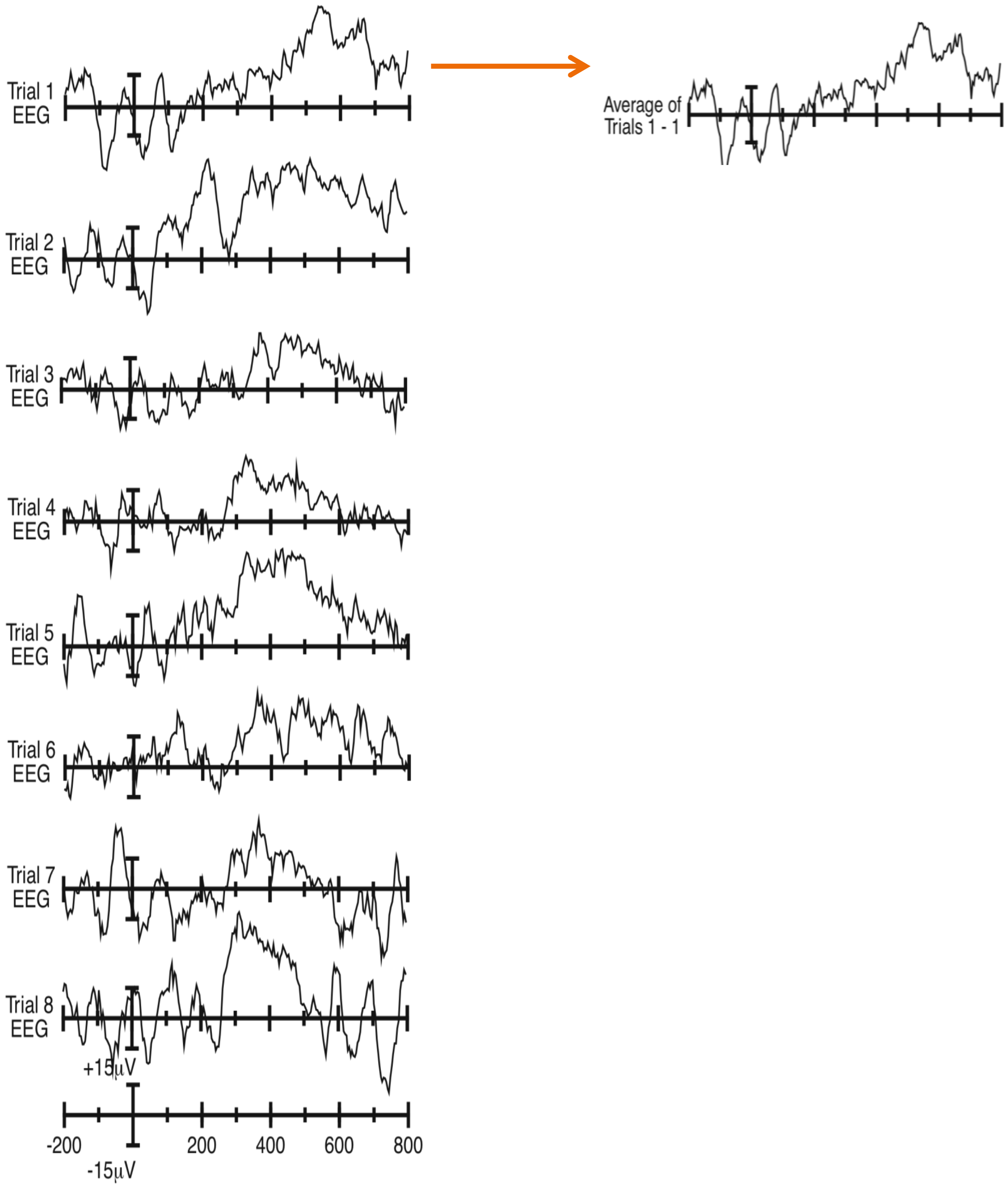
Averaging over trials improves the signal-to-noise ratio (SNR)

EEG: Event-Related Potential (**ERP**)
MEG: Event-Related Field (**ERF**)

Evoked activity over trials



ERPs in real life



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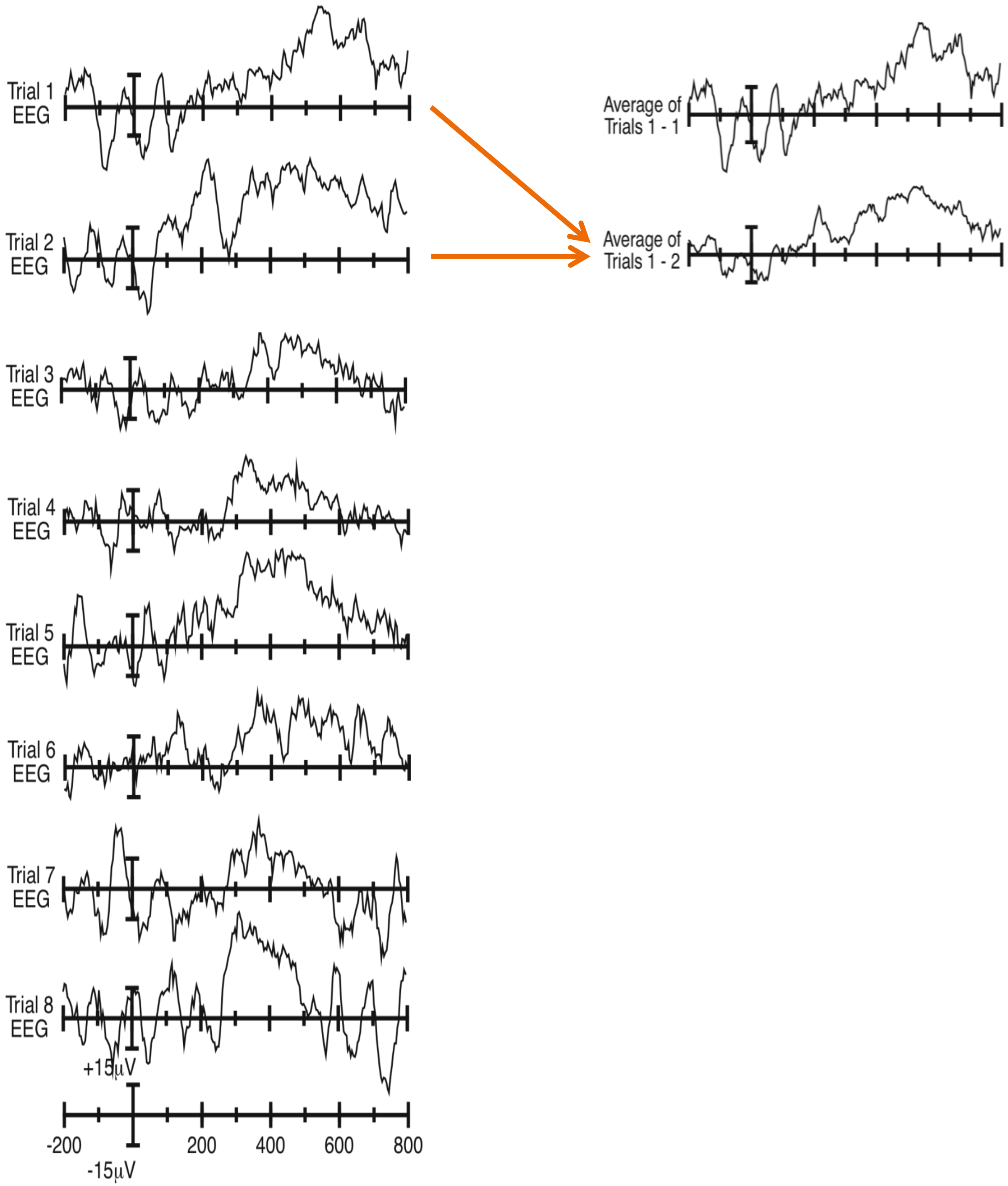

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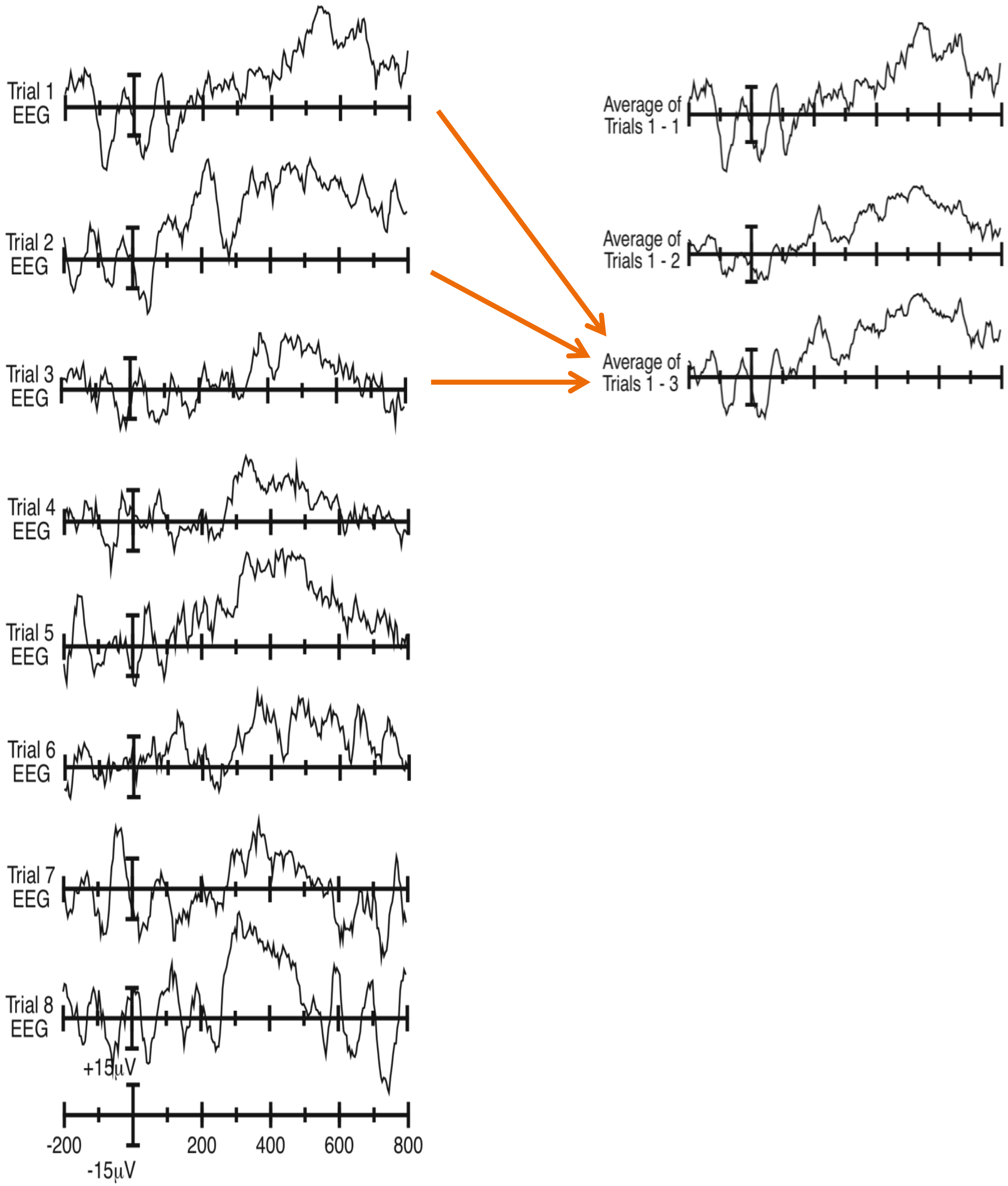

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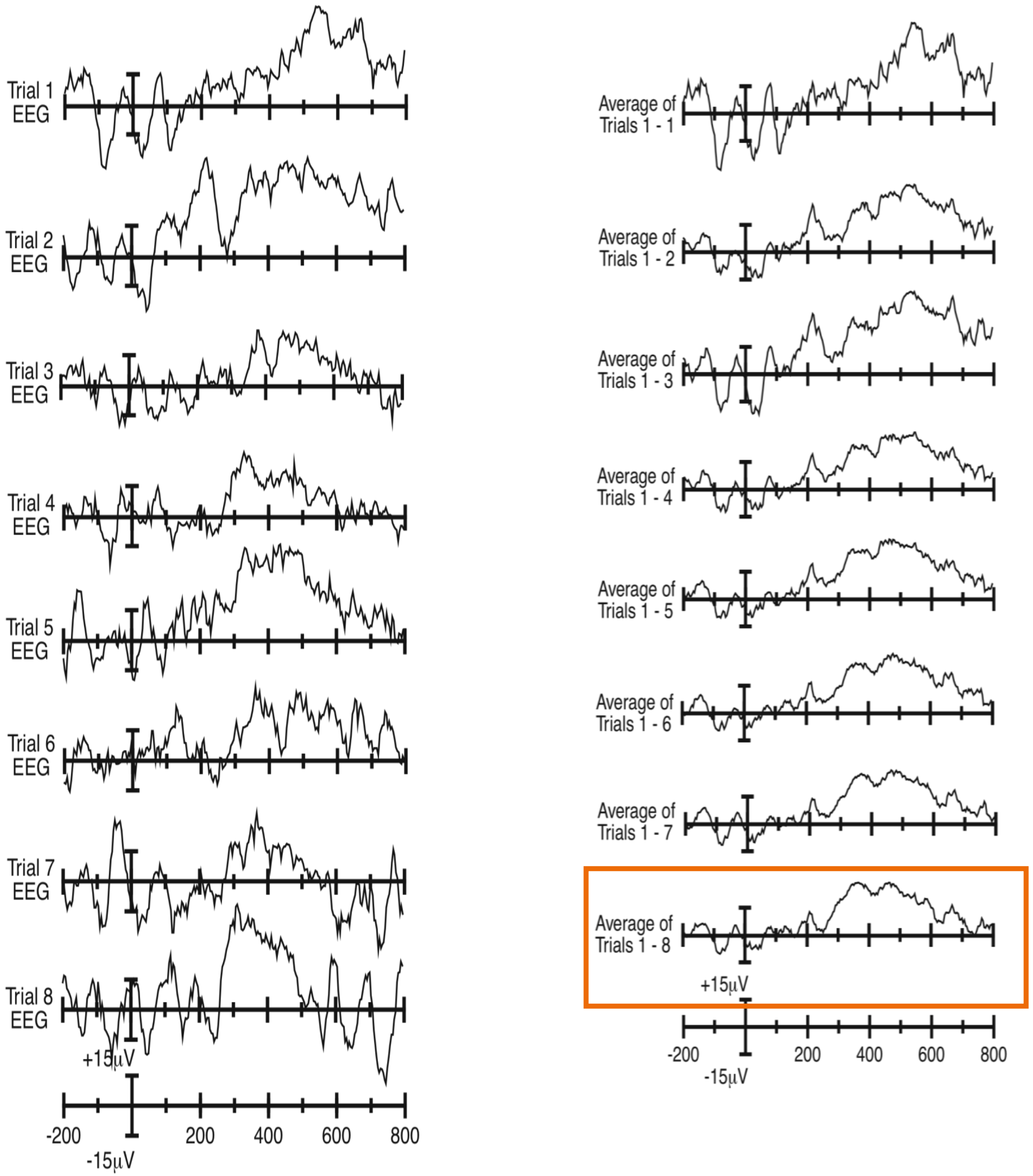
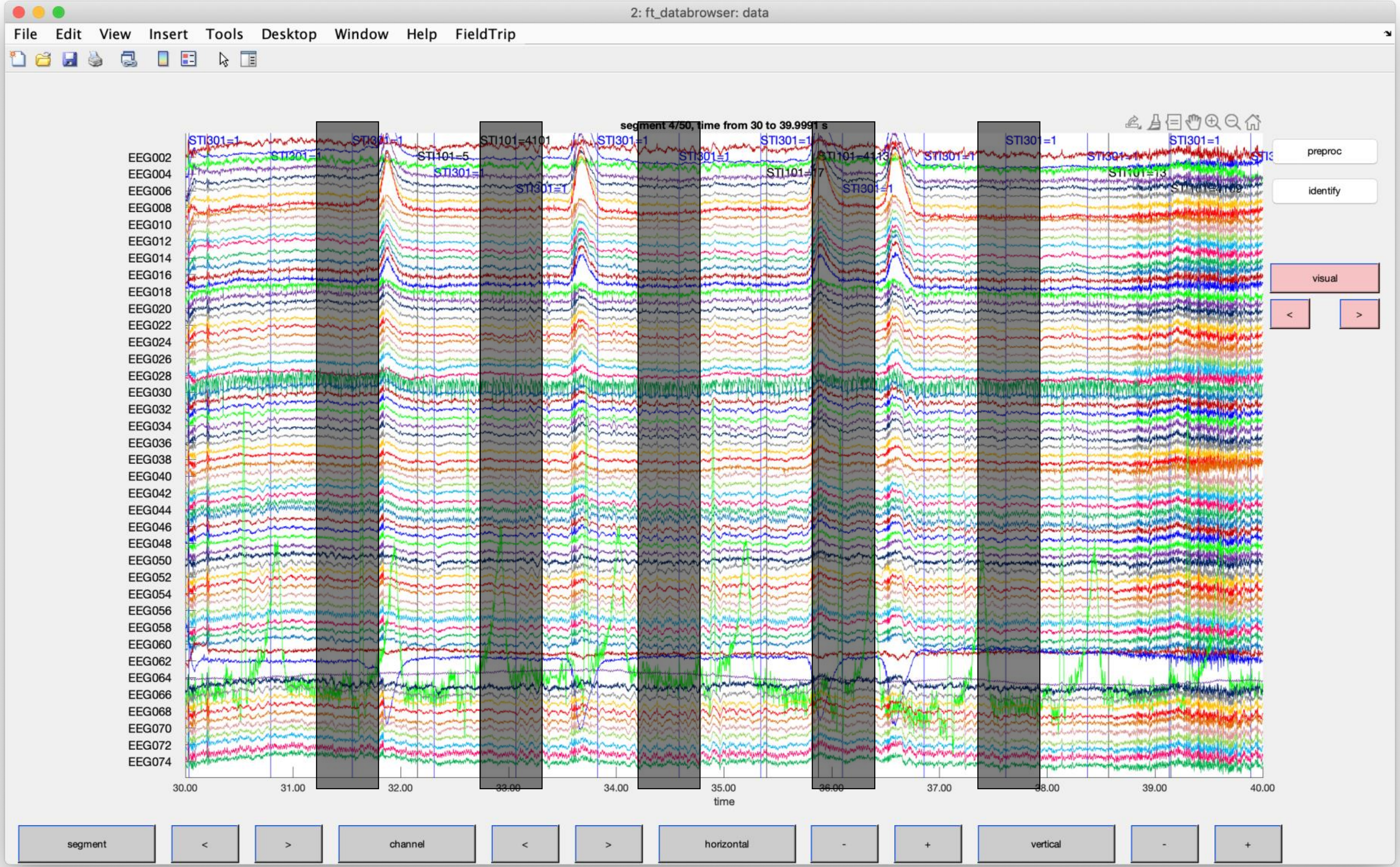


ERPs in real real life



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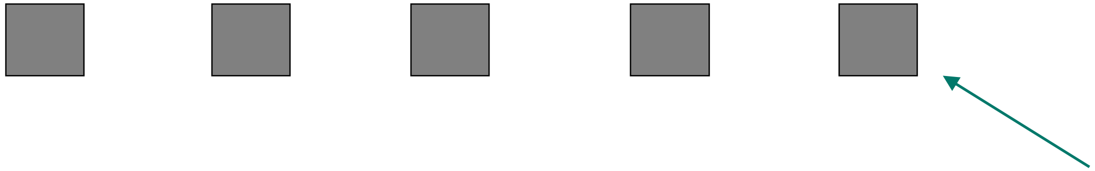
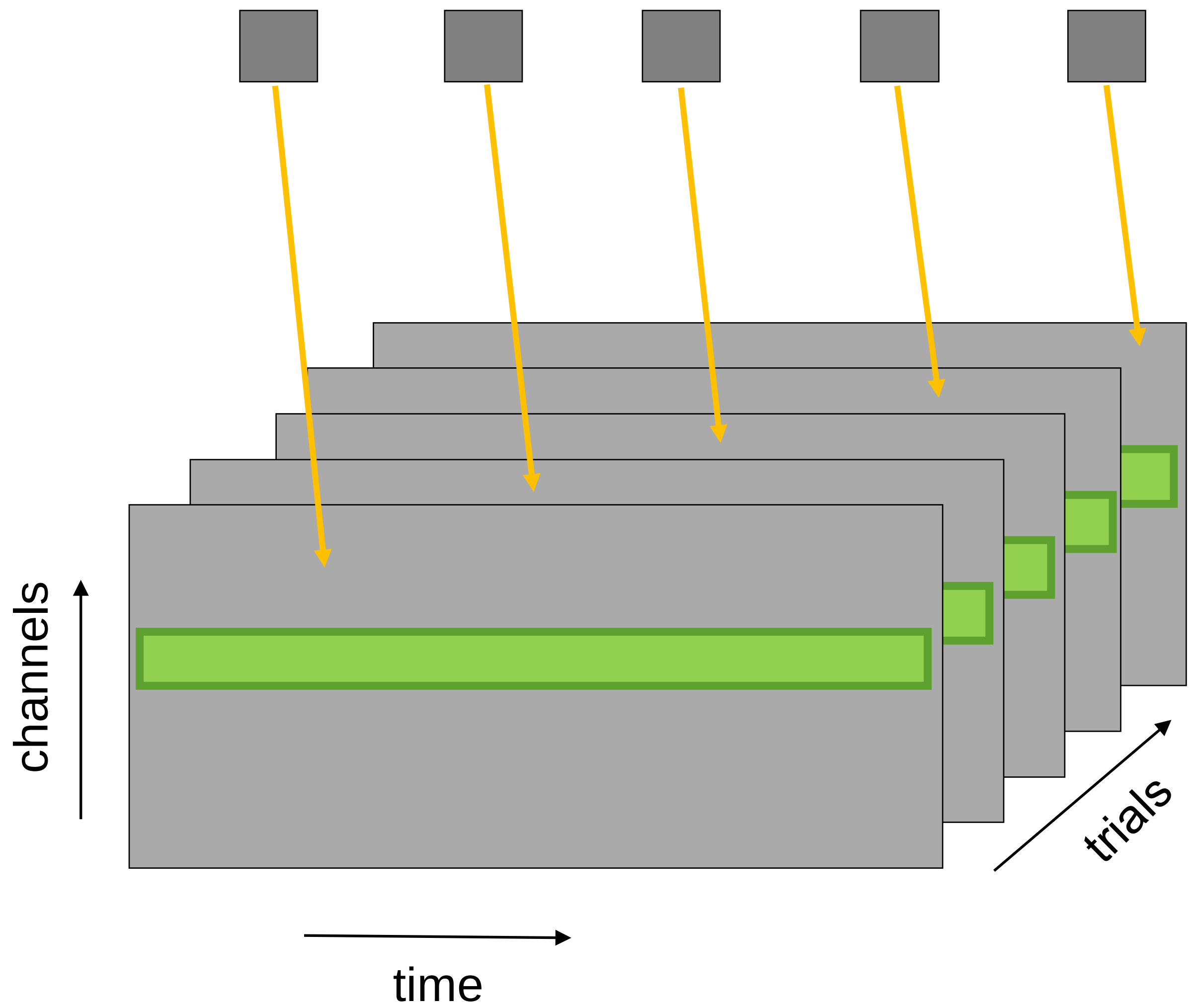
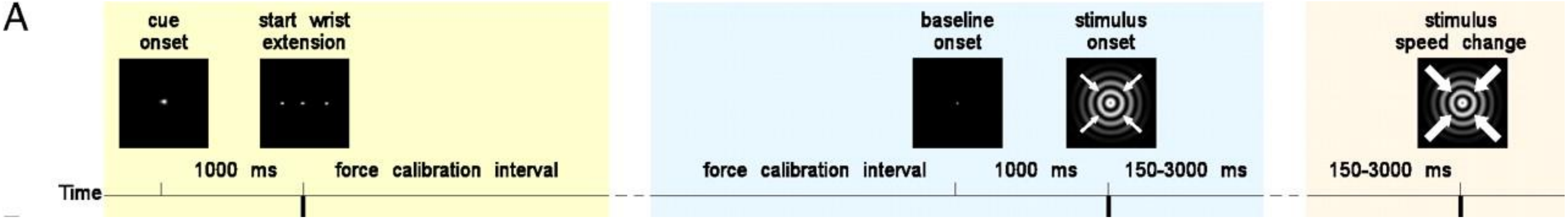


~ 100 channels
~ 1 second = 500 samples
So 100x500=50.000 numbers

ERPs in real real life



Analysing a simple event-related task



A trial starts by instructing participants whether they will have to extend their left or right wrist (trial type)

Participants extend out both wrists

After a random interval, a **visual stimulus** cues participants to move further with the wrist according to trial type

Let's analyse some data!

Demo of cleaning steps

Computing and plotting a visual-evoked ERF (this is MEG data)

You can find all of this on the Fieldtrip website! www.fieldtriptoolbox.org

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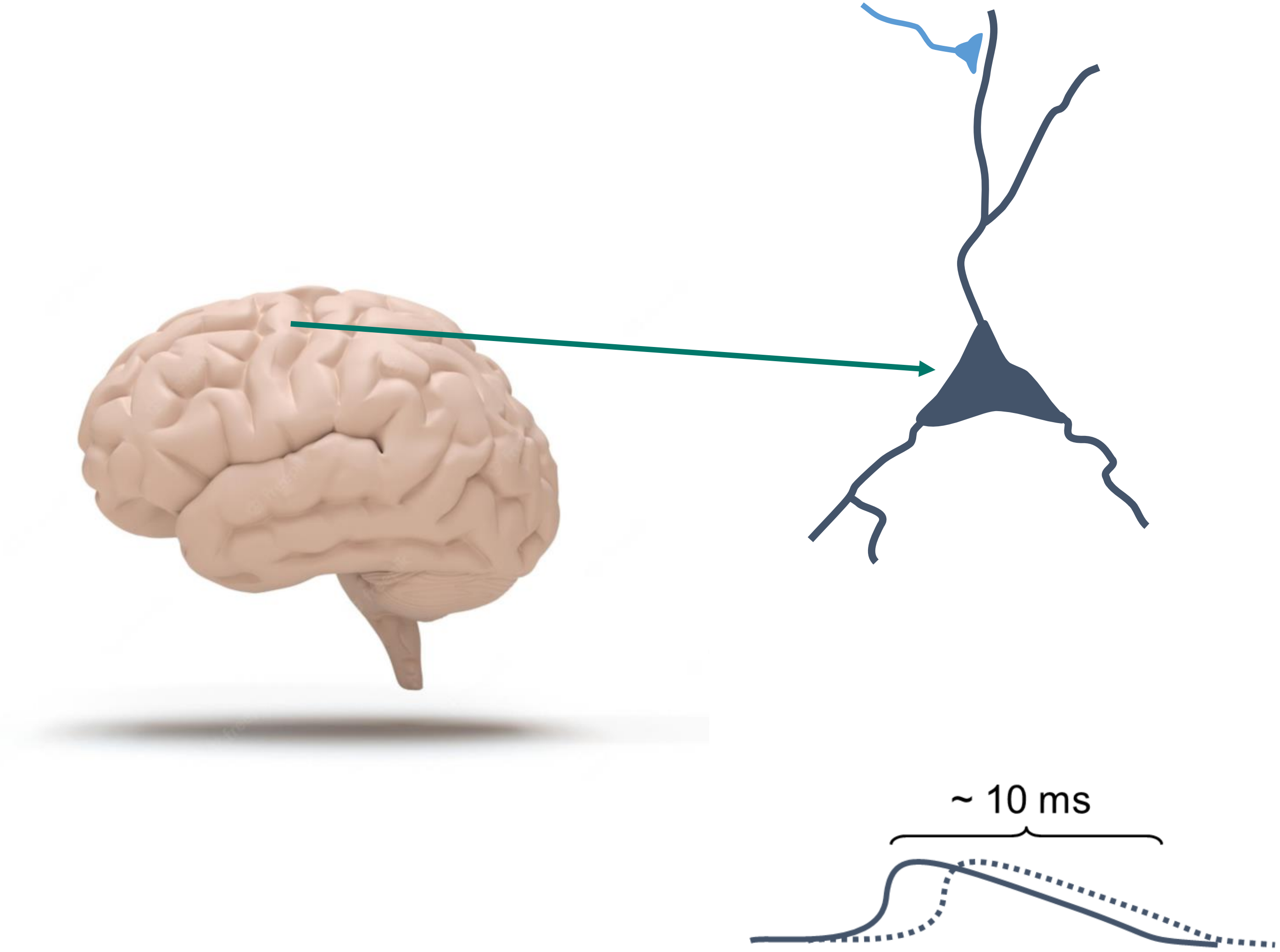
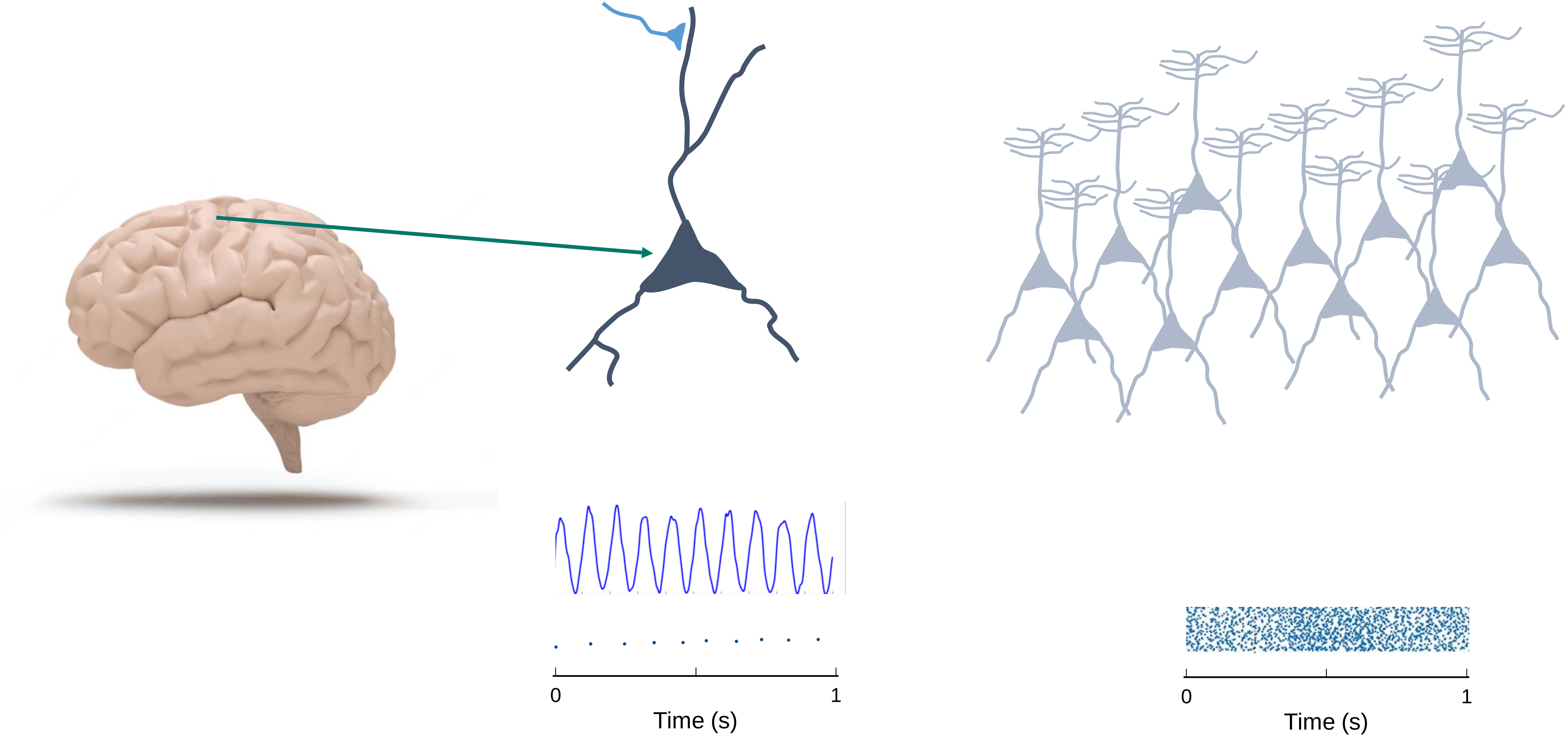
Bonus (if time allows)

Functional connectivity and phase coherence

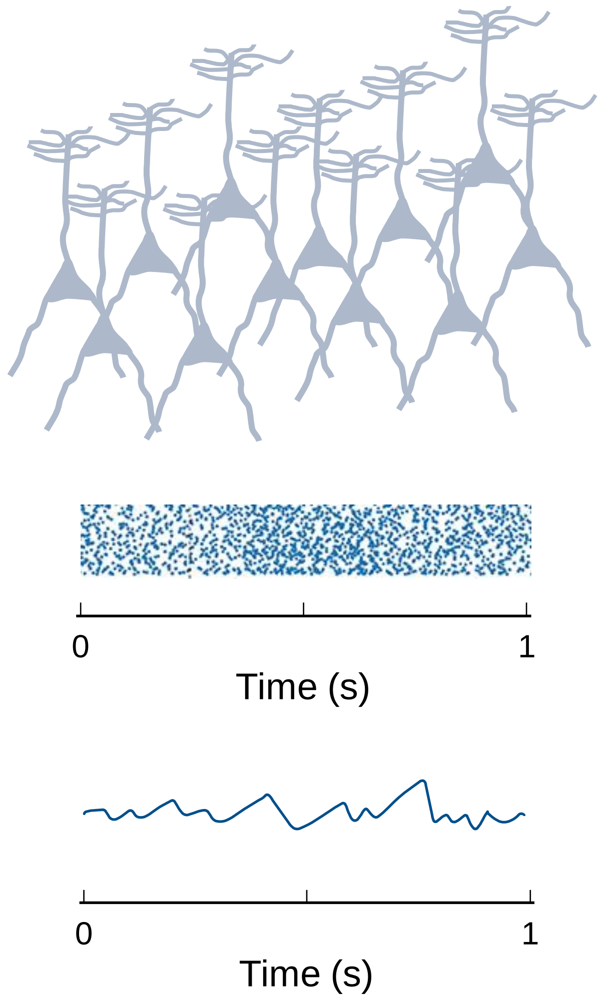
Develop an intuition about neural oscillations



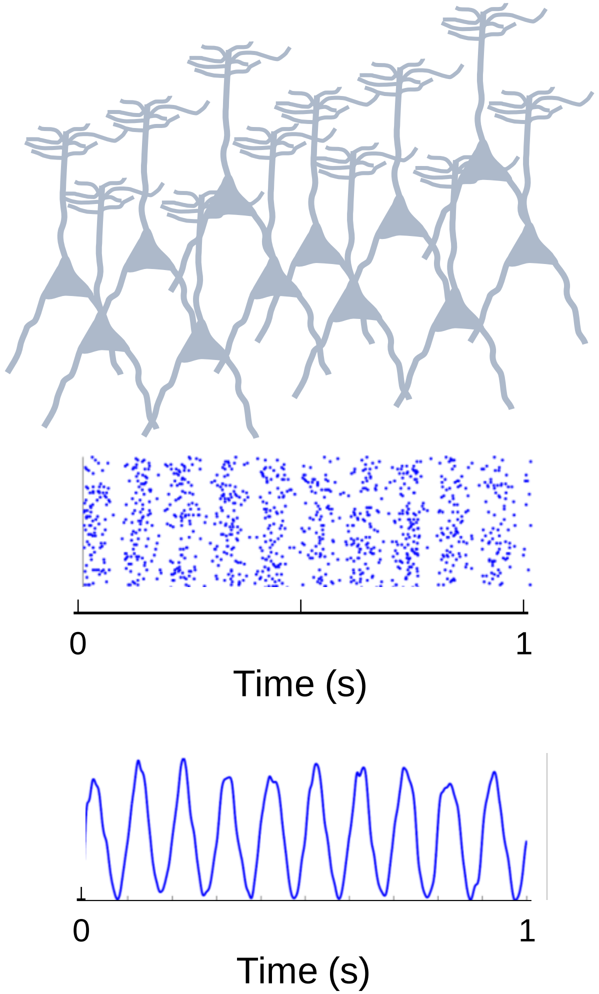
Develop an intuition about neural oscillations



local potential

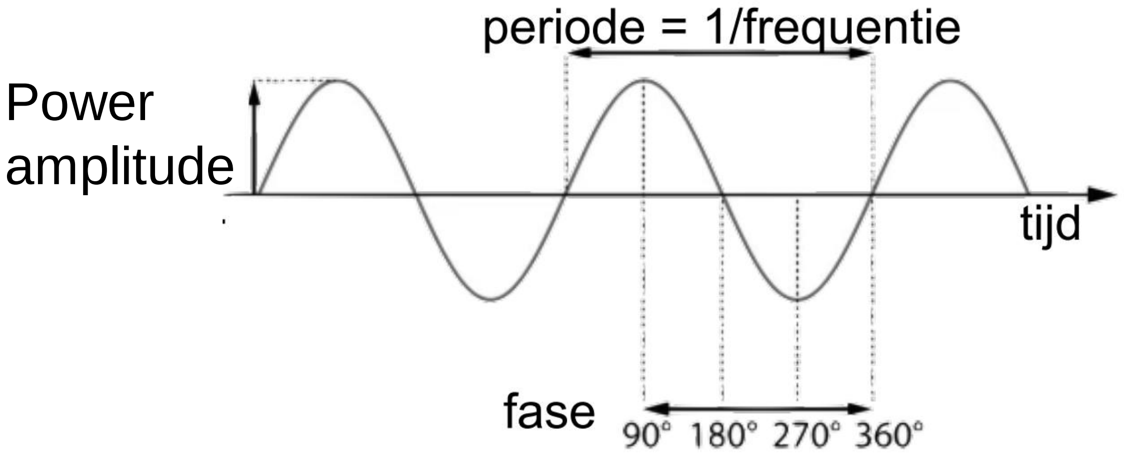


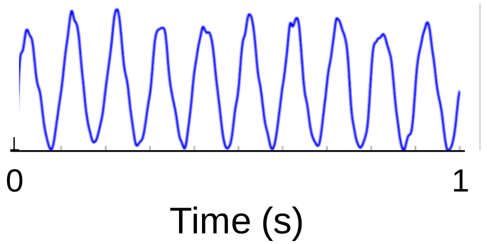
local
potential



Neural oscillations correspond to the **synchronized activity** (PSPs) of neurons

An oscillation has amplitude and phase

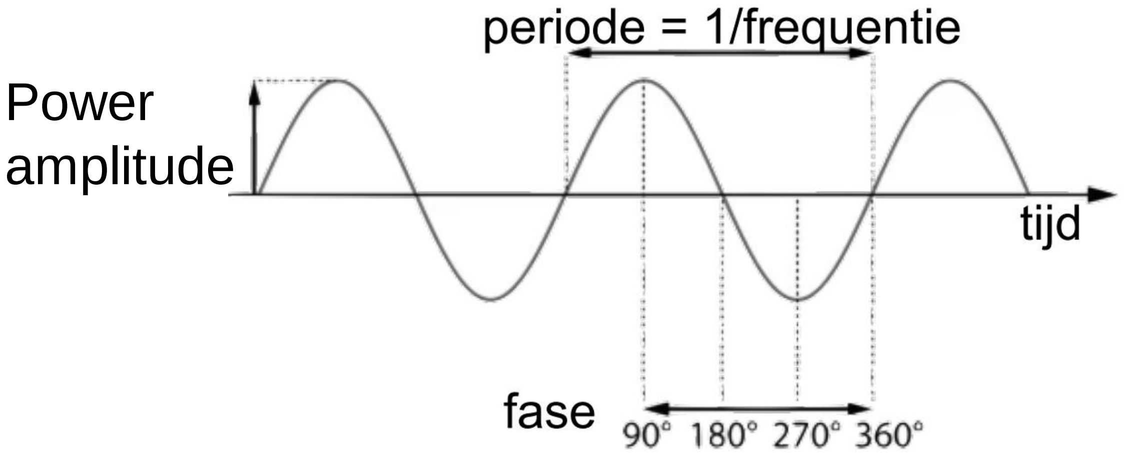


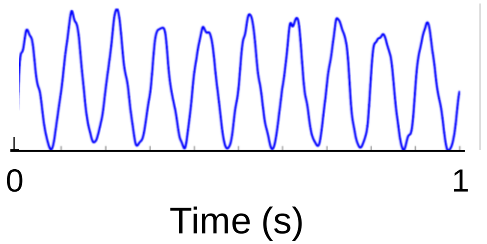


$$\text{Period (Hertz)} = \frac{1}{\text{frequency}}$$

Hint: number of peaks / 1 (second)

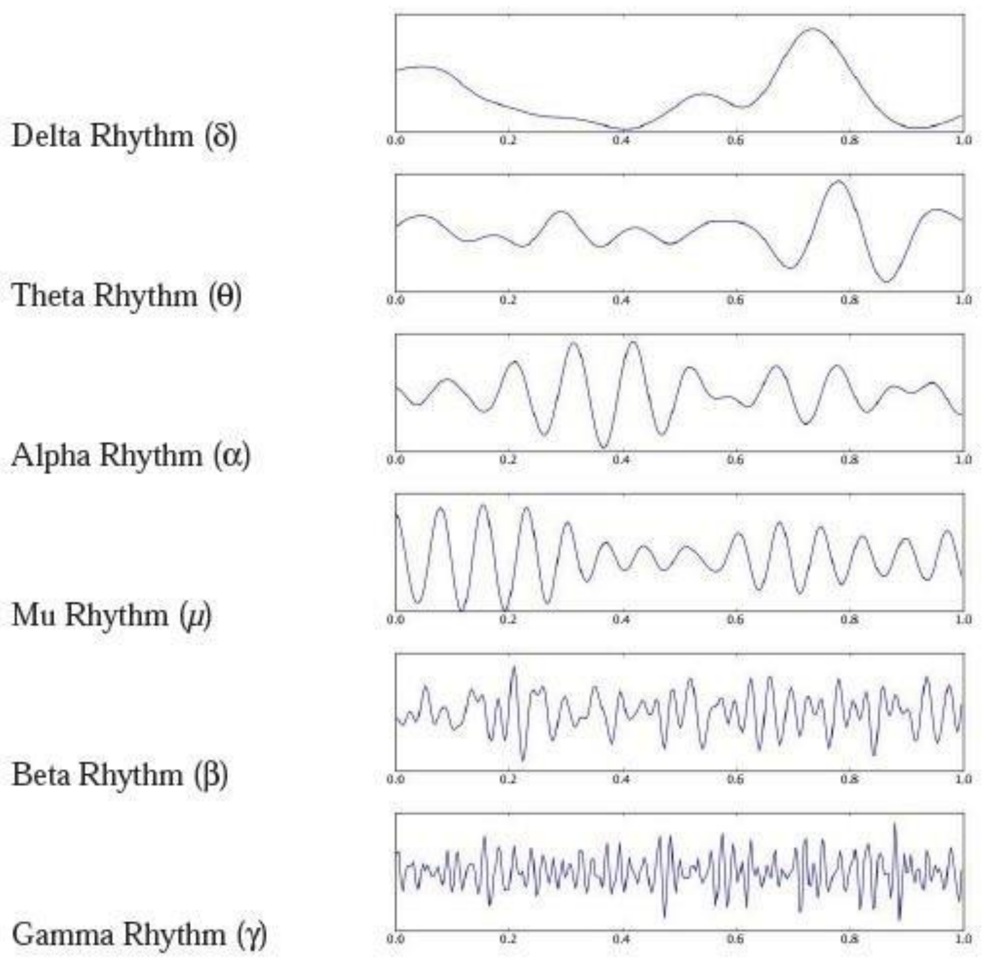
An oscillation has amplitude and phase





The period of the signal is **10 Hertz**.

Main canonical frequency bands



Researchers have given different labels to frequency bands, based on their functional associations

=

Different rhythms are **associated with** different functions or states

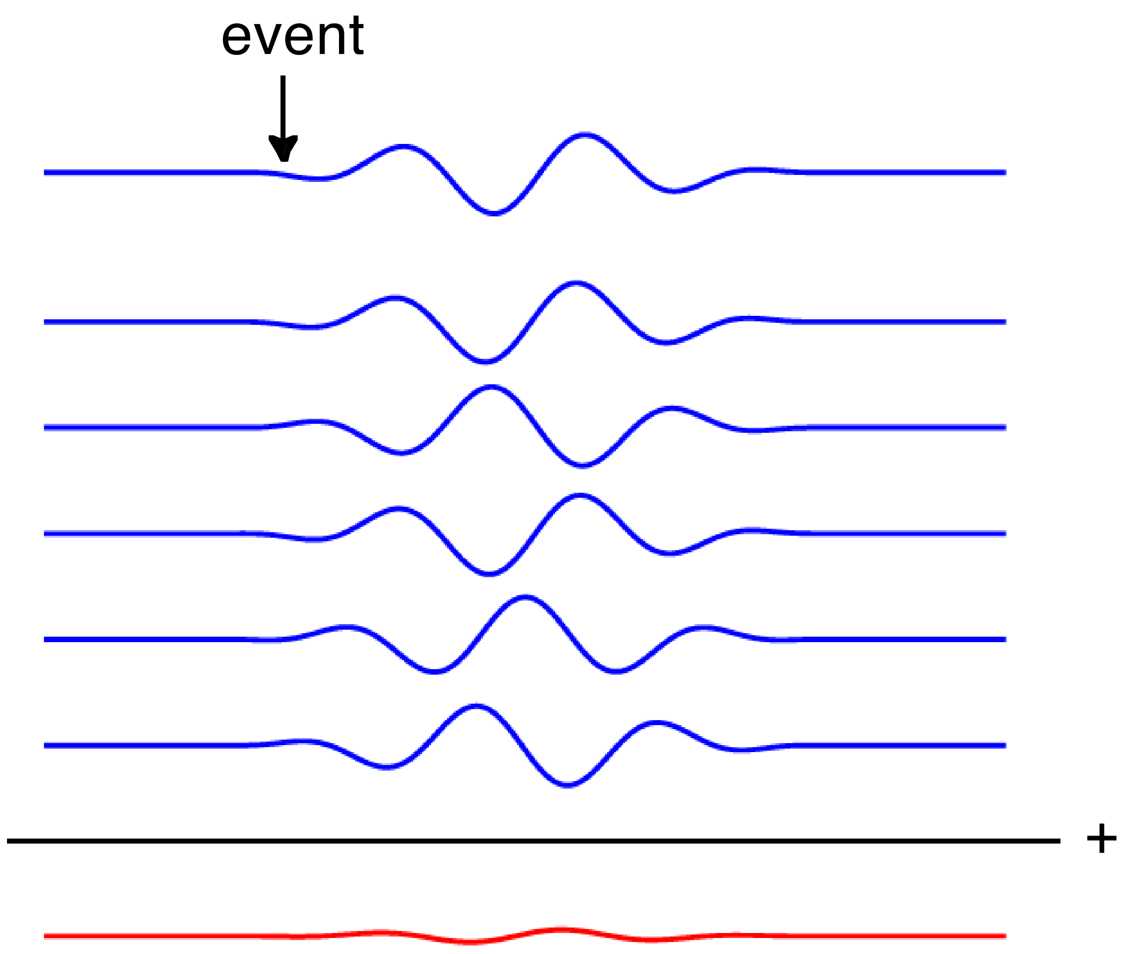
Examples:

Alpha → more power amplitude when drowsy, less when calculating maths

Beta → less when preparing to move

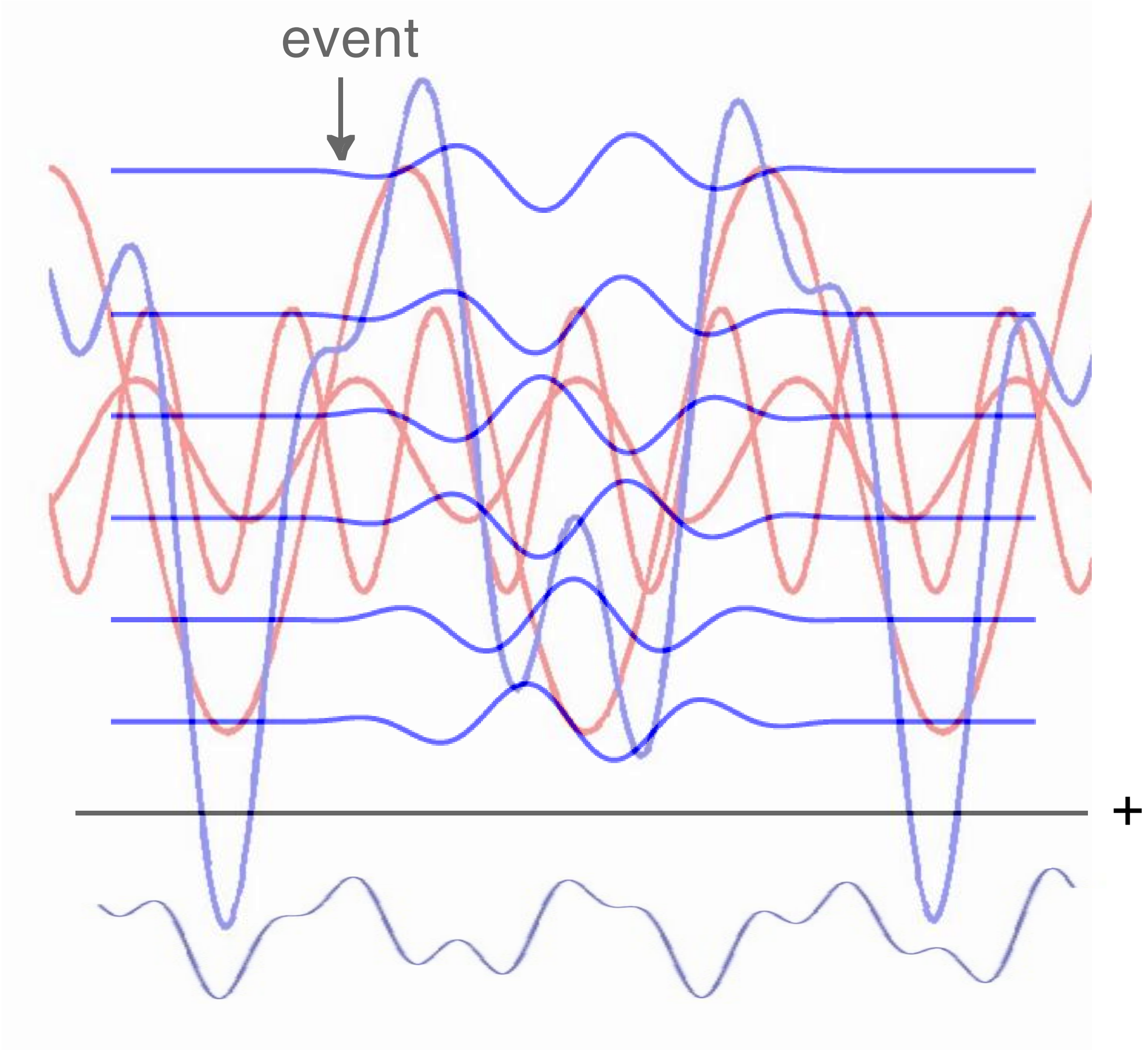
Gamma → more when processing visual information

Induced activity does not have a constant signal over trials



For certain tasks, we often have a different processing speed at each trial, so the amplitude and phase of the signal will differ.

Induced activity does not have a constant signal over trials

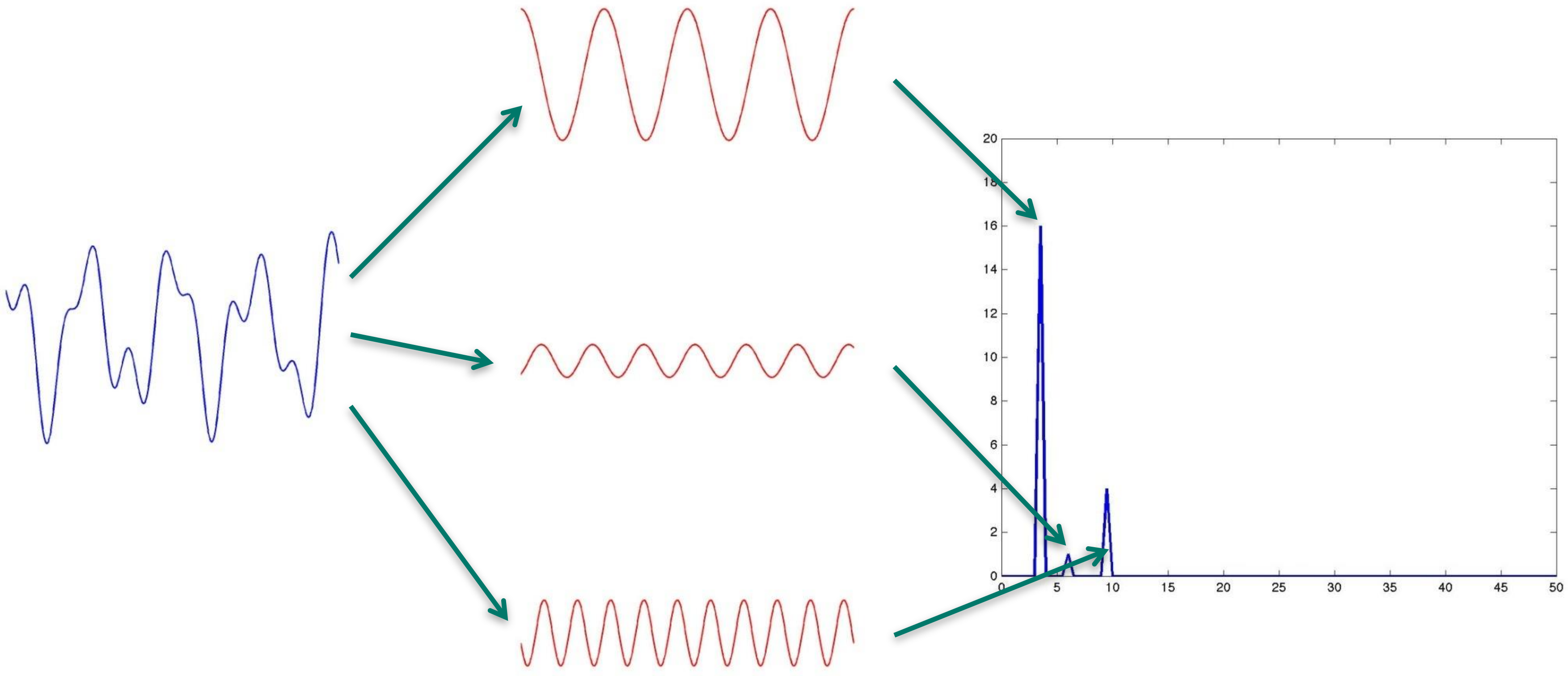


For certain tasks, we often have a different processing speed at each trial, so the amplitude and phase of the signal will differ.

There is also ongoing activity in different frequency bands.

…What now?

One option: spectral decomposition



Deconstructing a time domain signal into its constituent oscillatory components, a.k.a. **Fourier analysis**, to know **which frequency is present in the signal** and how much **for a given segment**.

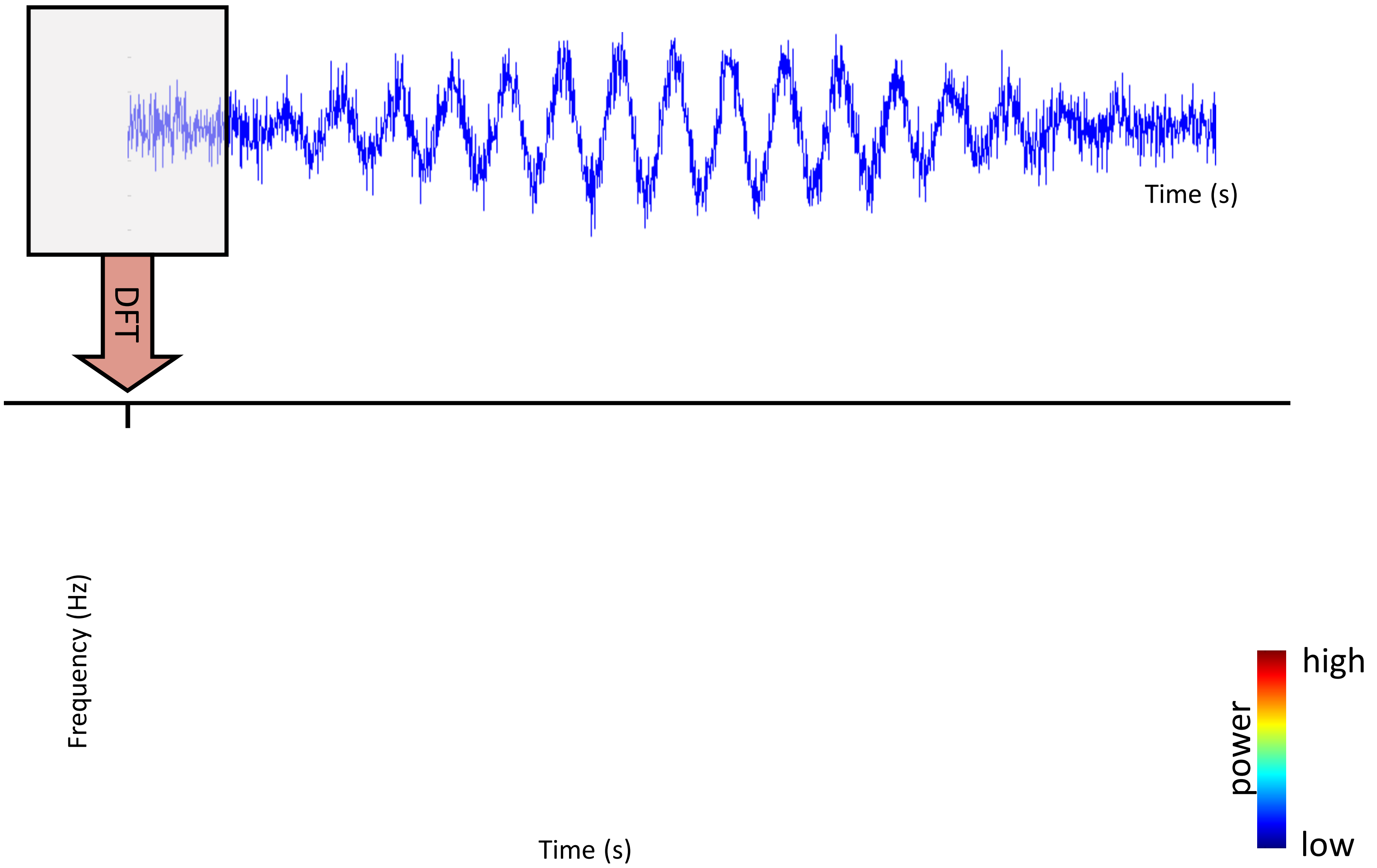
→ Express signal as function of frequency, rather than time

Another option: Time-frequency analysis

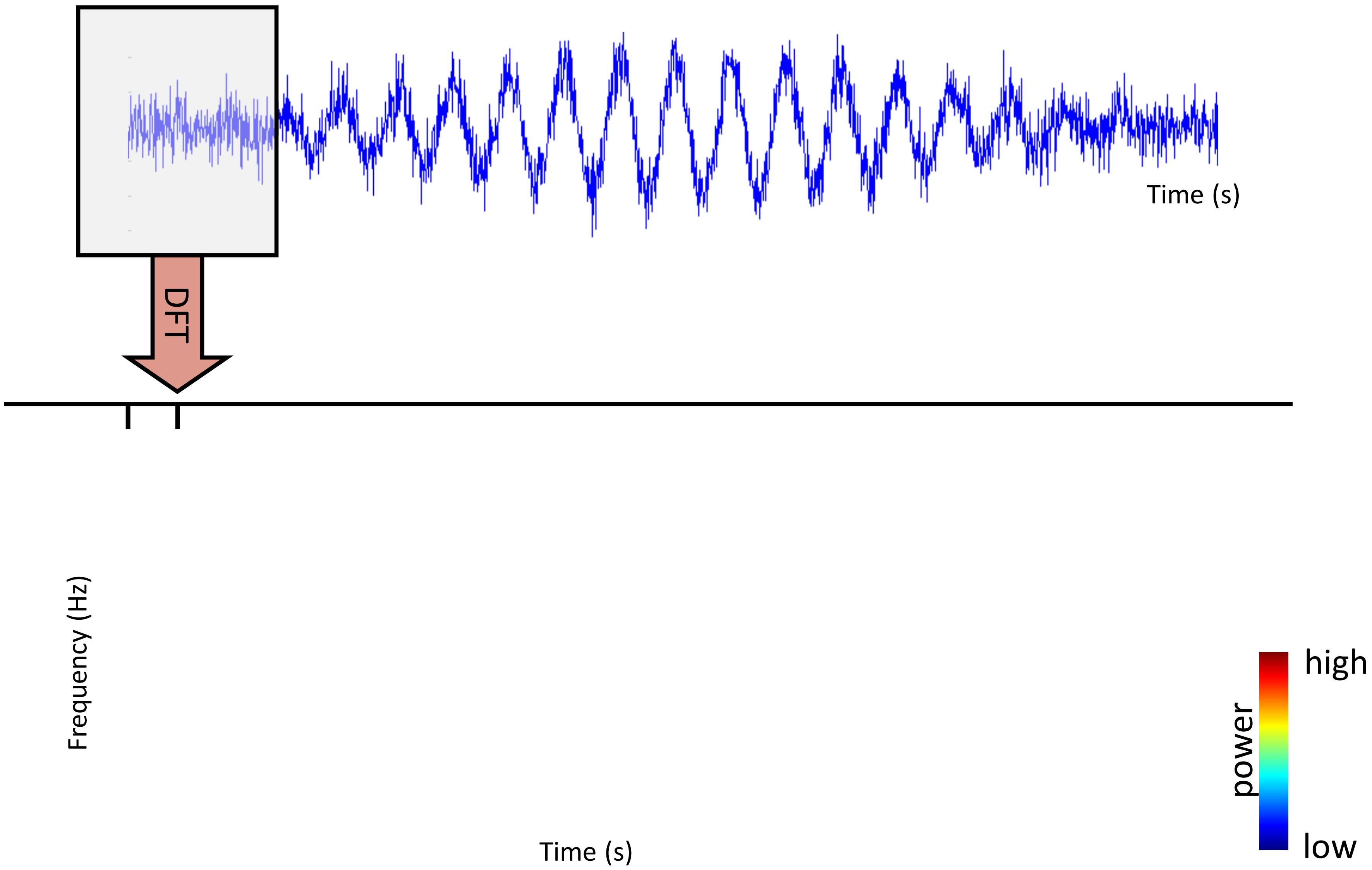
Typically, brain signals are not ‘stationary’ and we wish to measure a dynamic effect over time.

We divide the measured signal in shorter time segments and apply Fourier analysis to each signal segment with a sliding window.

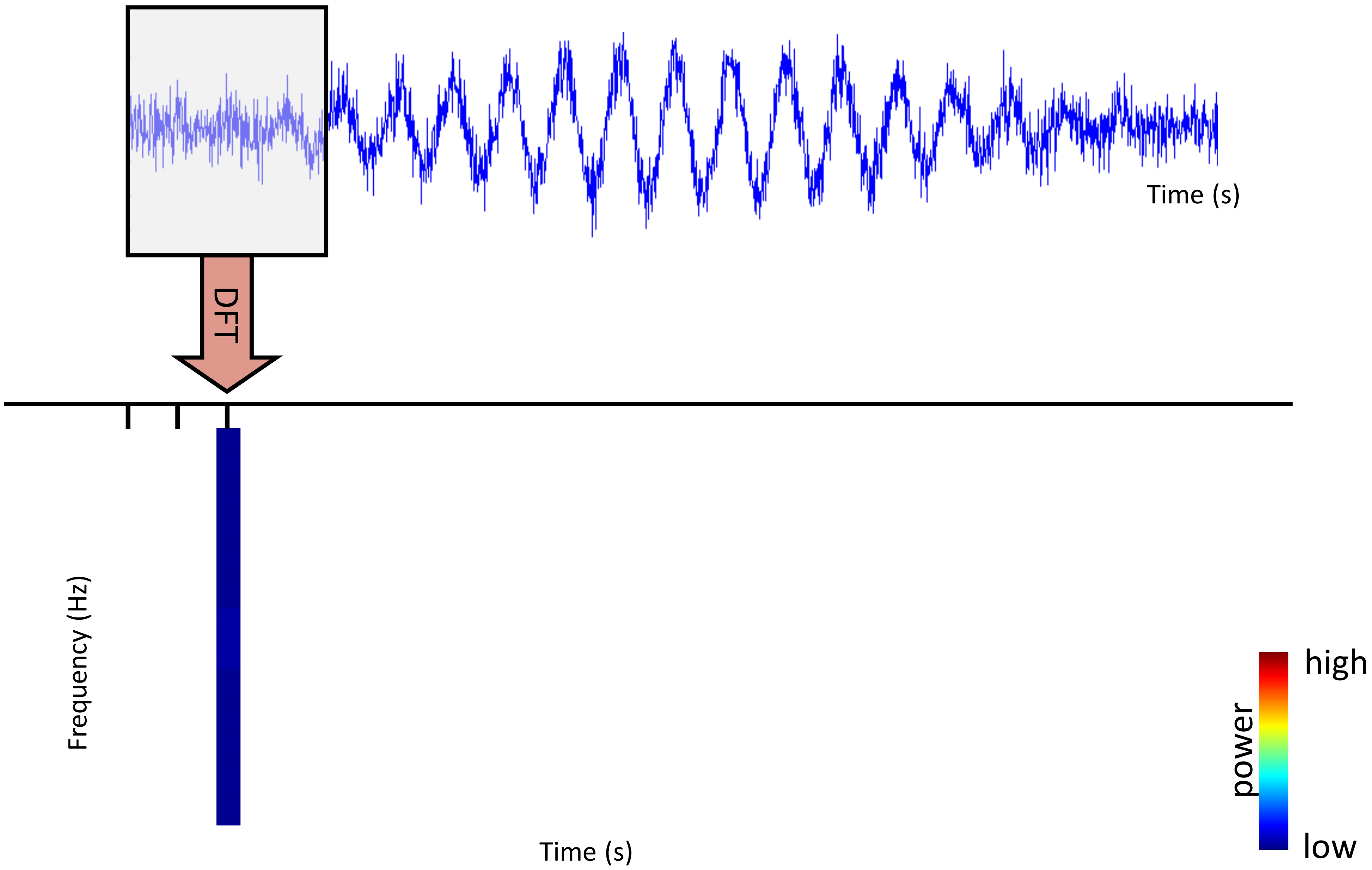
Time-frequency analysis



Time-frequency analysis

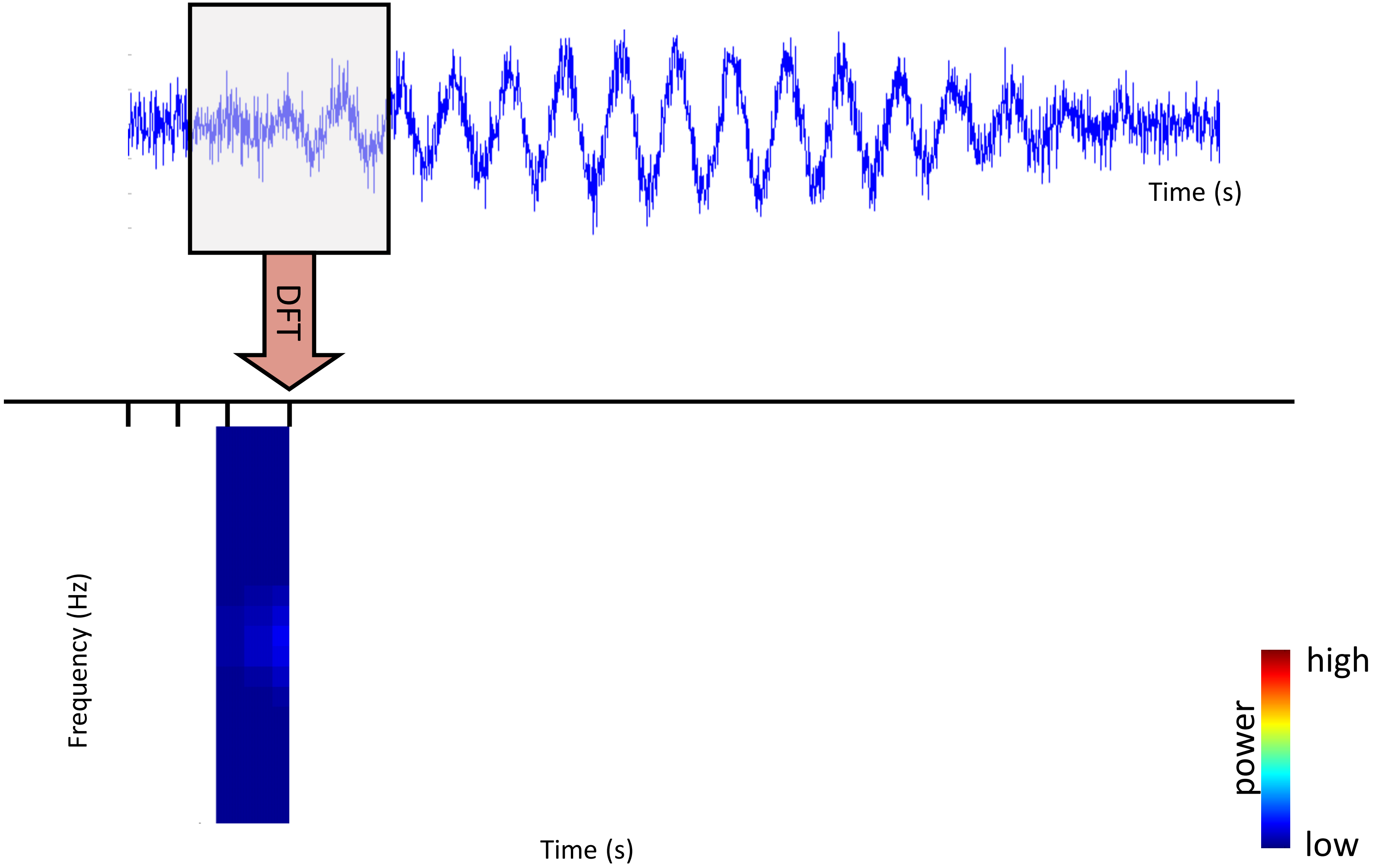


Time-frequency analysis



Column =
One time-window
(e.g., 0 to 0.1 seconds)

Time-frequency analysis



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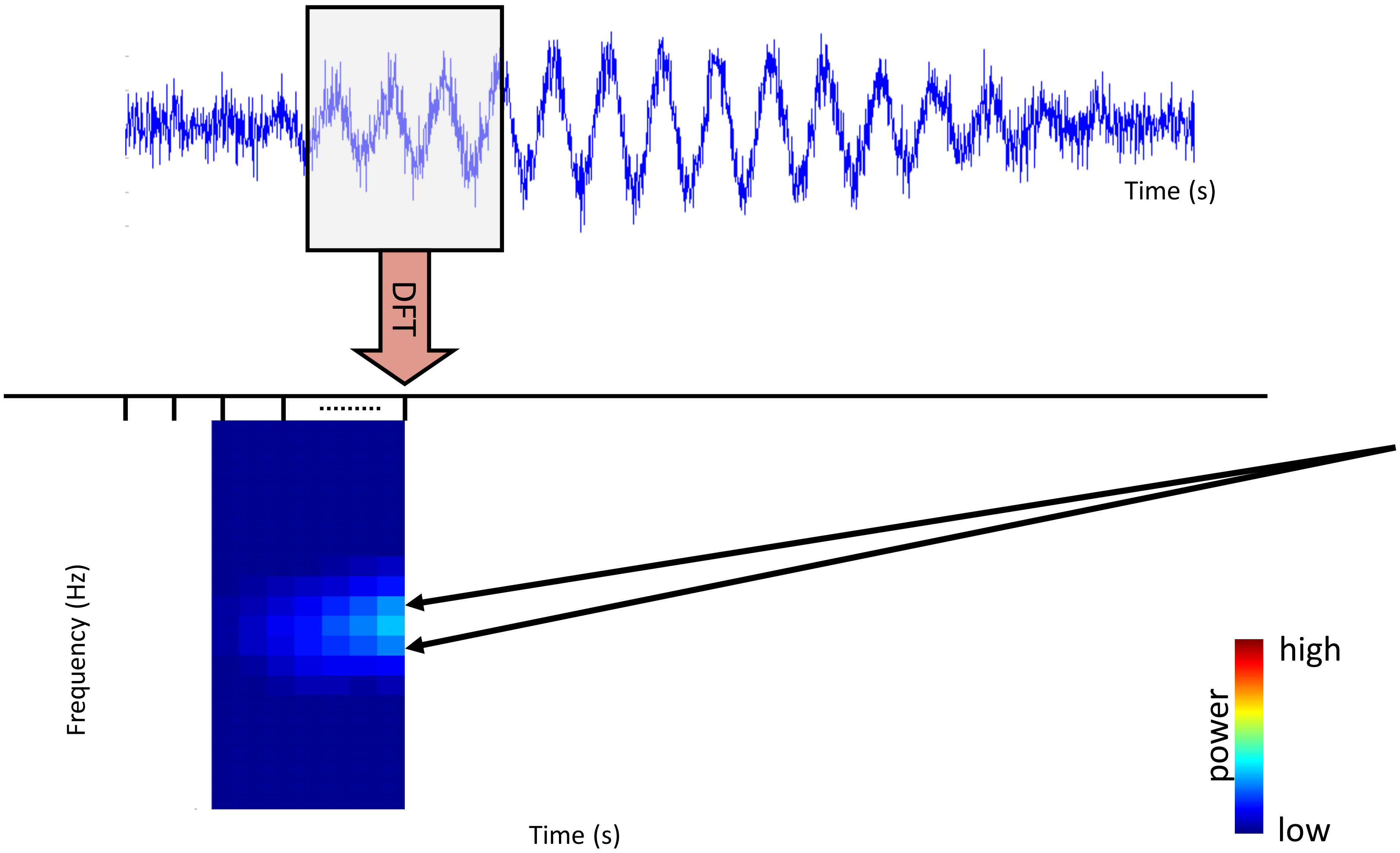
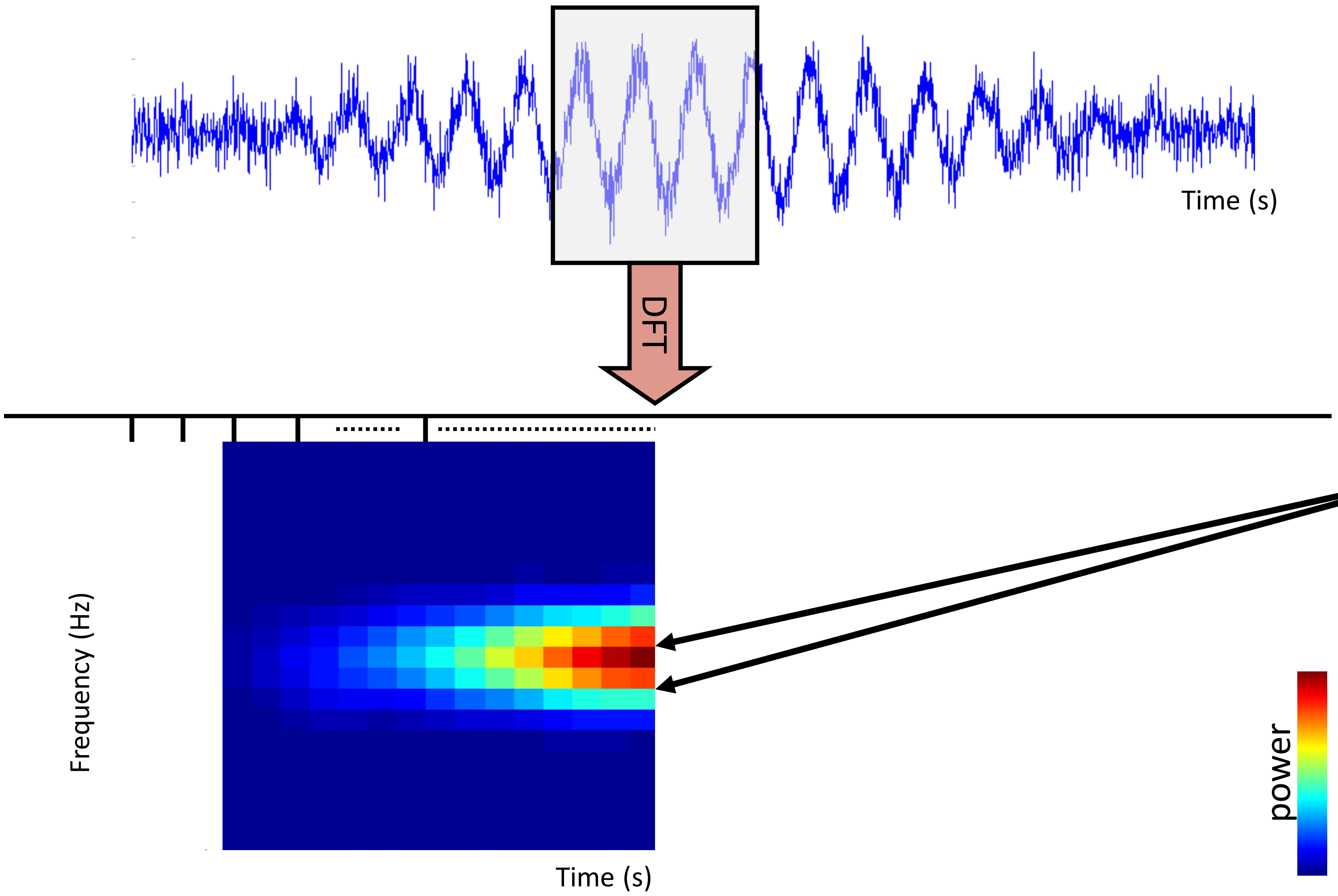
Time-frequency analysis



Row =
One frequency band
(e.g., 0-5 Hertz)

Time-frequency analysis



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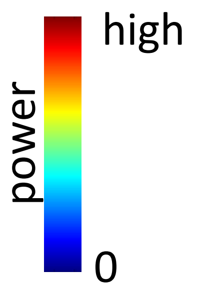

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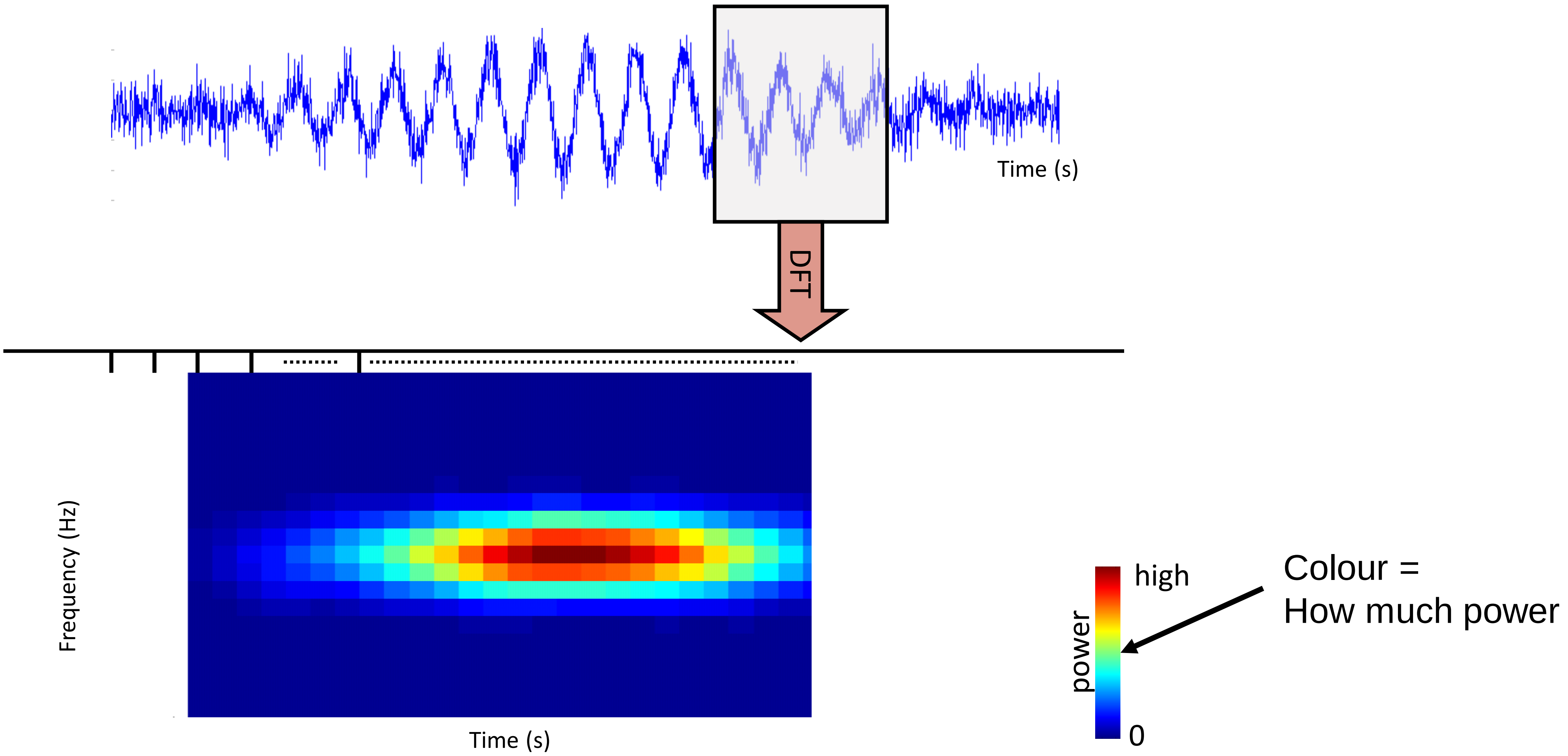
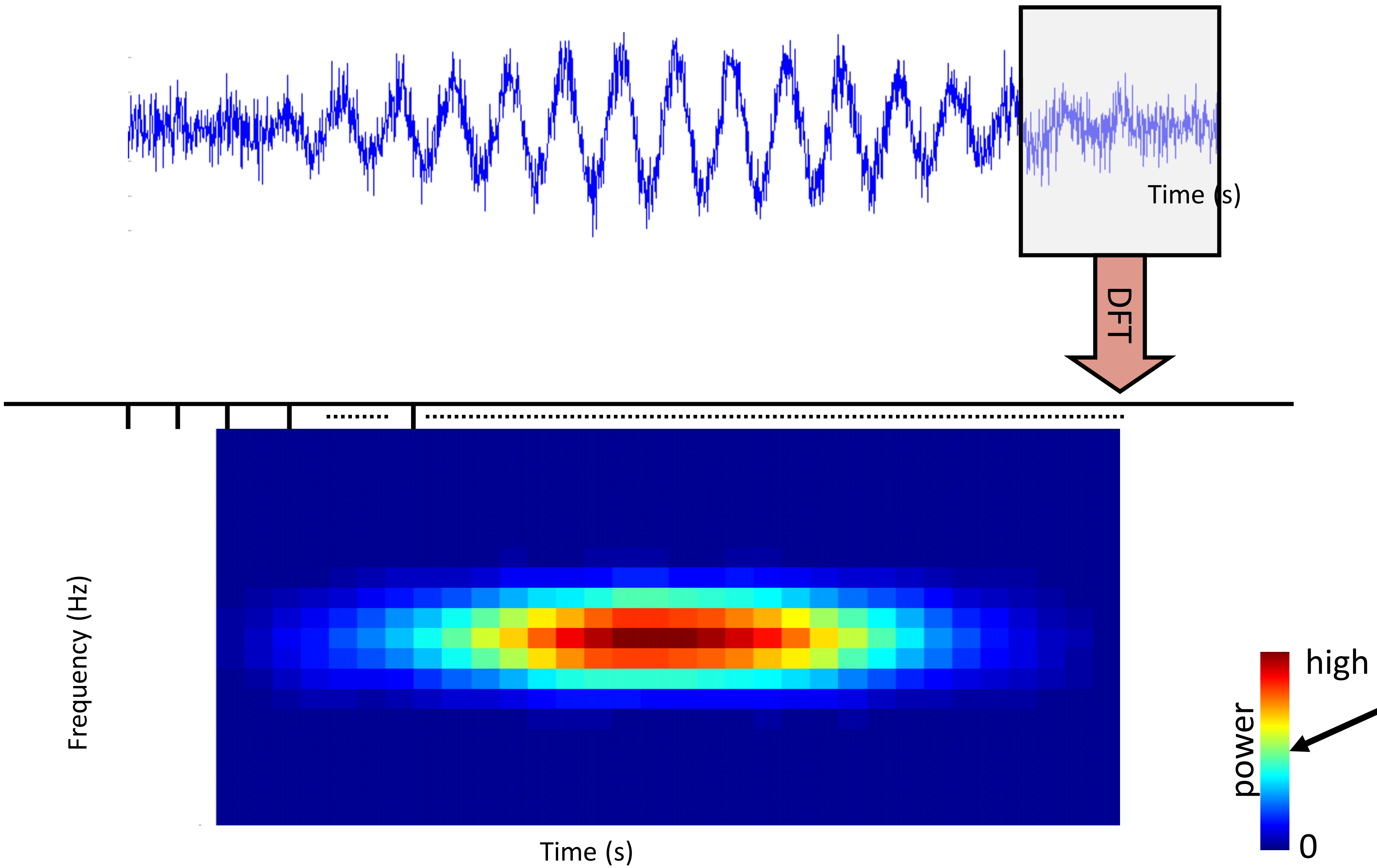
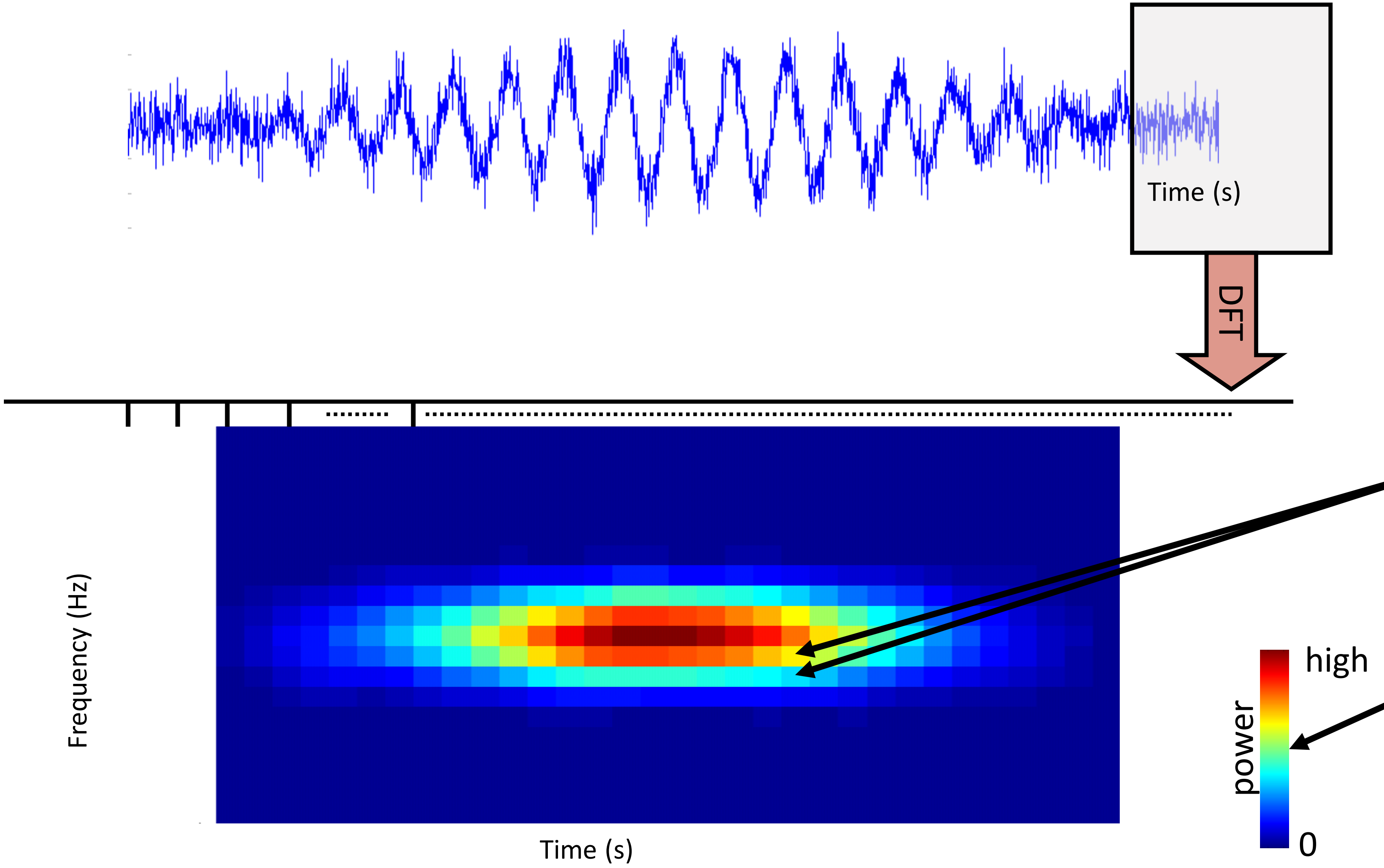


Time-frequency analysis



Colour =
How much power

Time-frequency analysis



Column =
One time-window
(e.g., 0 to 0.1 seconds)

Row =
One frequency band
(e.g., 0-5 Hertz)

Colour =
How much power

Evoked vs induced activity

Evoked activity: average over trials to get feature of interest

Oscillation has same polarity relative to the stimulus each time – you can obtain the feature in the oscillation by averaging

Induced activity: averaging does not extract feature because the phases vary across trials

First, we need to compute the TFR of each trial, and then average to get the feature of interest.

Let’s analyse some data!

Time-frequency analysis

You can find all of this on the Fieldtrip website! www.fieldtriptoolbox.org

Summary

Post-synaptic potential (PSP): when a neuron receives input from another neuron and this changes its potential

We measure the PSPs using EEG (electric current) and/or MEG (magnetic field)

Evoked activity has constant signal for each trial → look at the signal by averaging over trials (in relevant channels)

Induced activity is not constant over trials, the phase and amplitude of the signal change

Neural oscillations correspond to the **synchronized activity** of neurons (evoked or induced)
- Different frequency bands are **associated with** different functions

We can decompose the signal of a segment using **Fourier analysis**

Time-frequency analysis allows us to look at how the amplitude of the frequencies increases and decreases over time (segments)