

# Foundations of Psychophysiology

Part 8.2: Electrocortical measures

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NEUROADAPTIVE  
HUMAN-COMPUTER  
INTERACTION



Brandenburg  
University of Technology  
Cottbus - Senftenberg

# Psychophysiology: Electrocortical measures

## The electroencephalogram

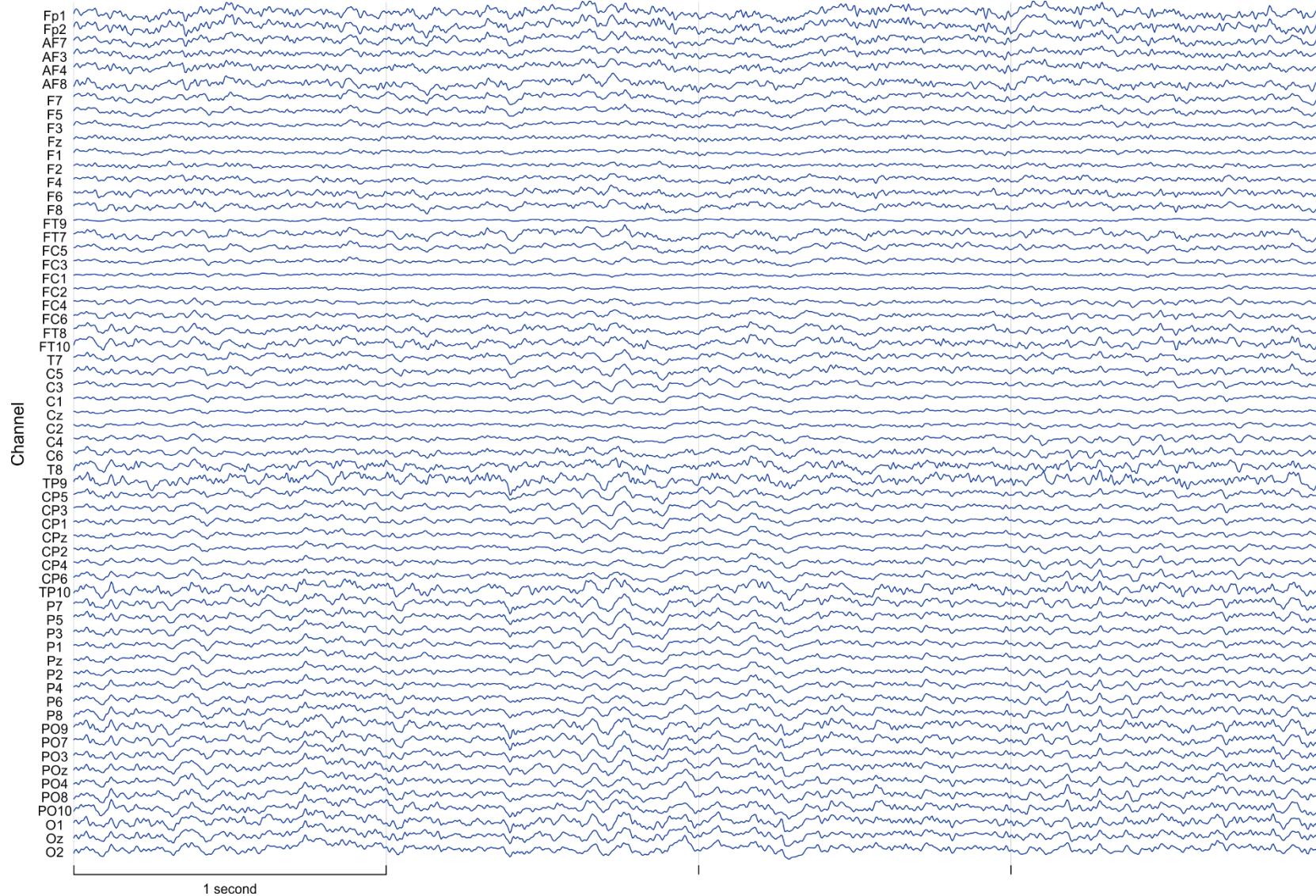


Figure by Irkrol is in the public domain

# Psychophysiology

## Electrocortical measures

Recording an EEG

Spontaneous EEG activity

Frequency domain analysis

Time domain analysis

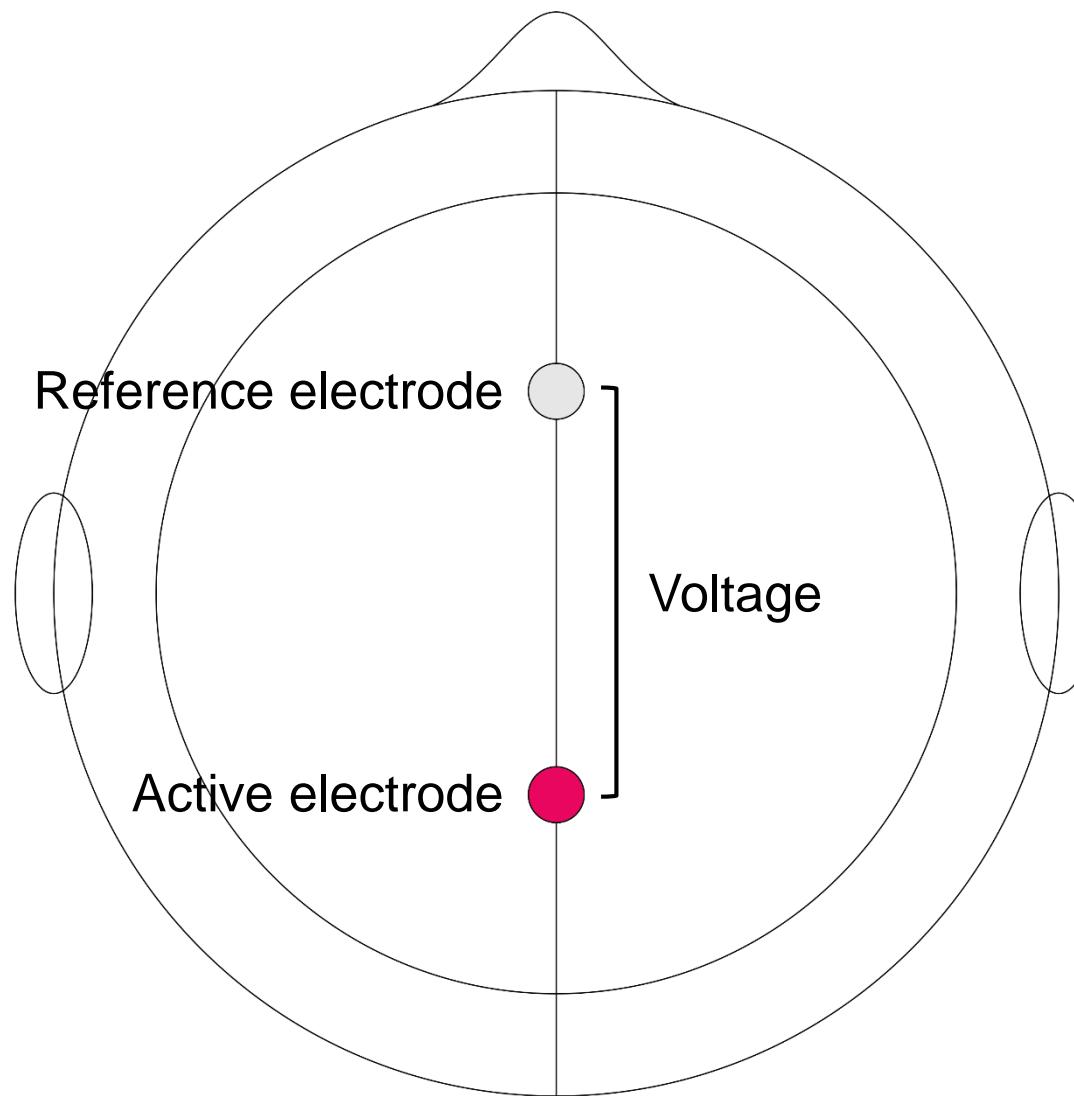
Time-frequency analysis

Time-time analysis

# Psychophysiology: Electrocortical measures

## Recording an EEG

# Psychophysiology: Electrocortical measures: Recording Electrodes



# Psychophysiology: Electrocortical measures: Recording

## The reference electrode

“Active” electrodes are placed near “electrically active” regions to measure voltage relative to an “electrically neutral” reference (or ground) electrode.

However, there is no “electrically neutral” reference location on the human body.

Use a reference location that has a good connection.

Use a single reference for all electrodes.

Use a reference location that is common practice for the experiment you’re conducting.

# Psychophysiology: Electrocortical measures: Recording

## Reproducing electrode positions

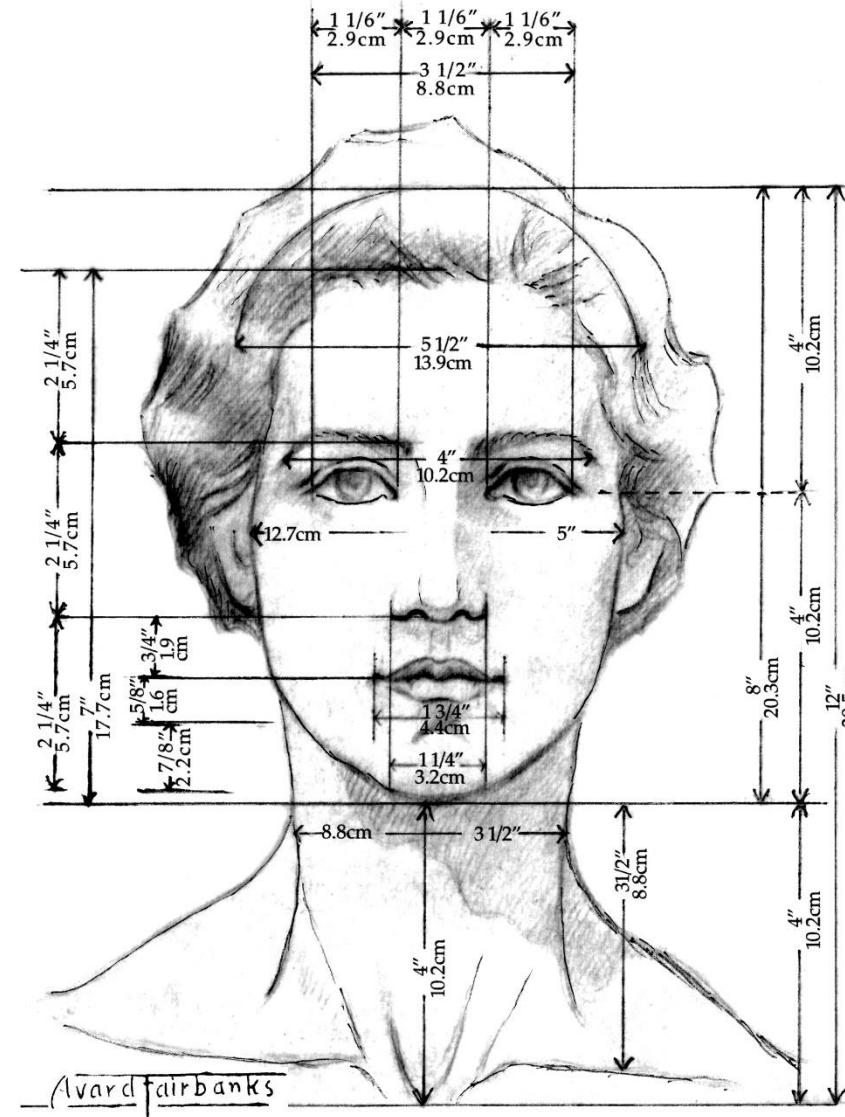
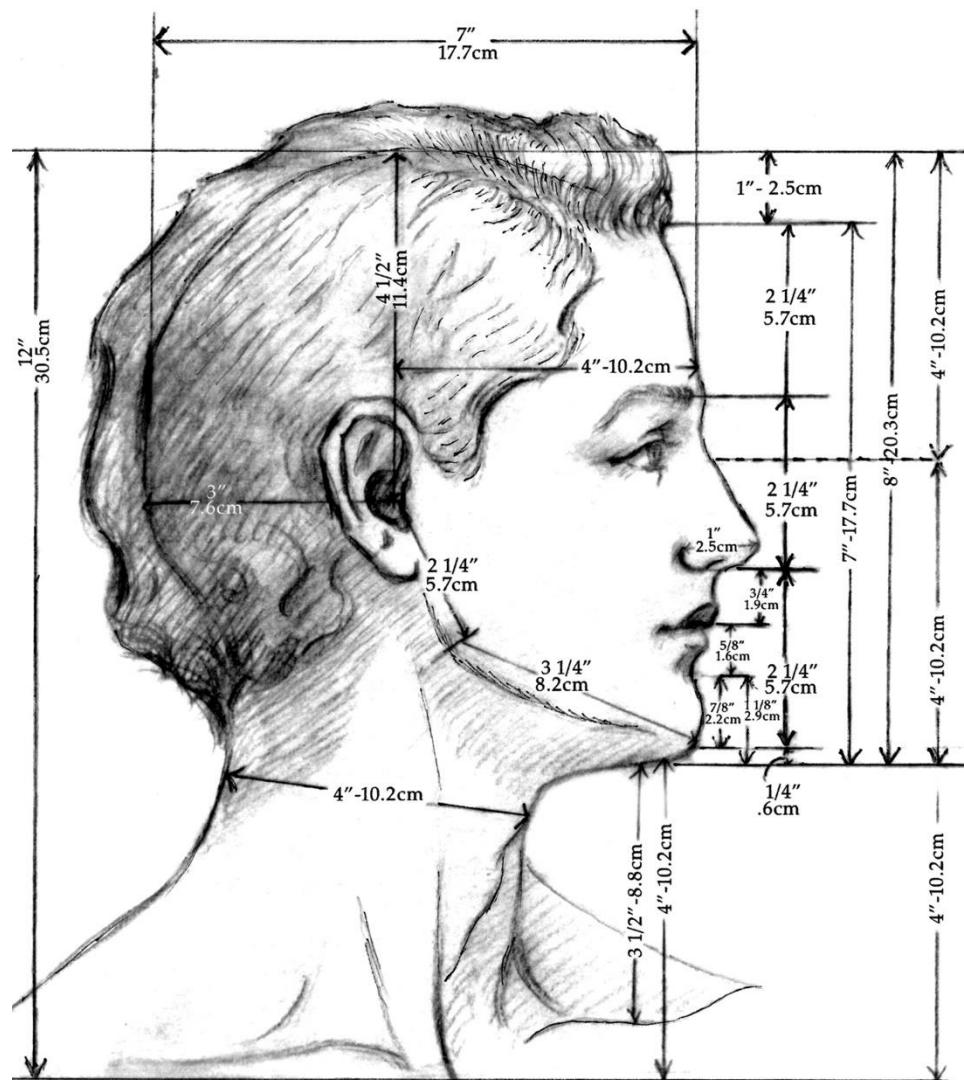


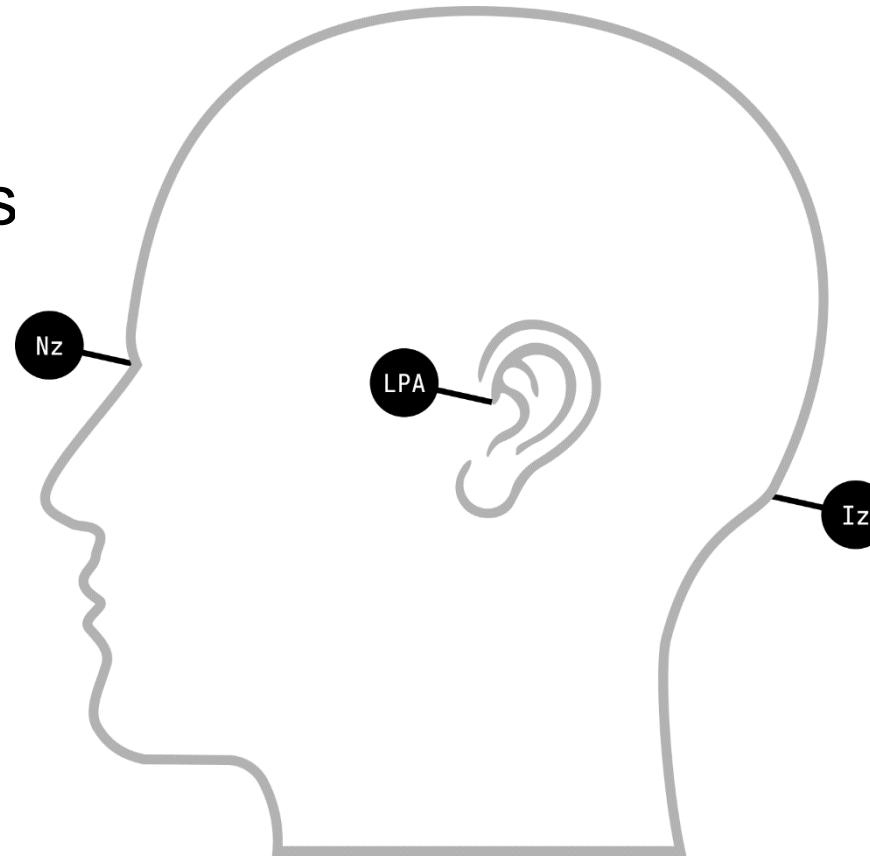
Figure by Avard T. Fairbanks is licensed under [CC BY-SA 4.0](#) (as per the executor of his estate, Eugene F. Fairbanks)

# Psychophysiology: Electrocortical measures: Recording

## The international 10-20 system

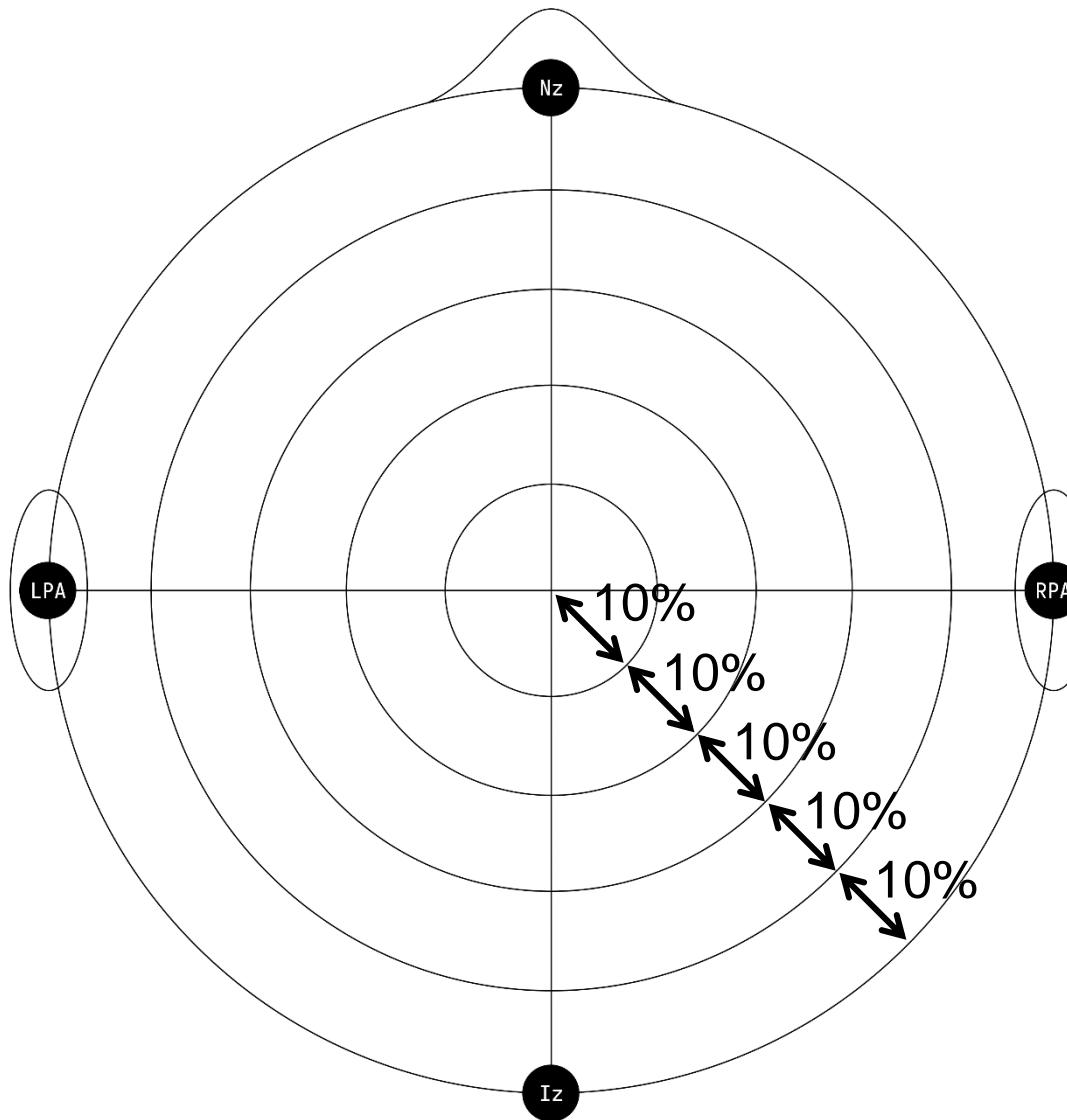
### Fiducials

- Nasion
- Pre-auricular points  
(left and right)
- Inion



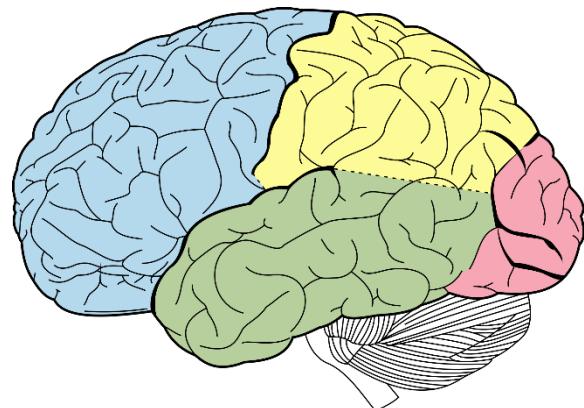
# Psychophysiology: Electrocortical measures: Recording

## The international 10-20 system



# Psychophysiology: Electrocortical measures: Recording

## The international 10-20 system



F – Frontal

C – Central

P – Parietal

O – Occipital

T - Temporal

Odd – Left

z – Midline

Even – Right

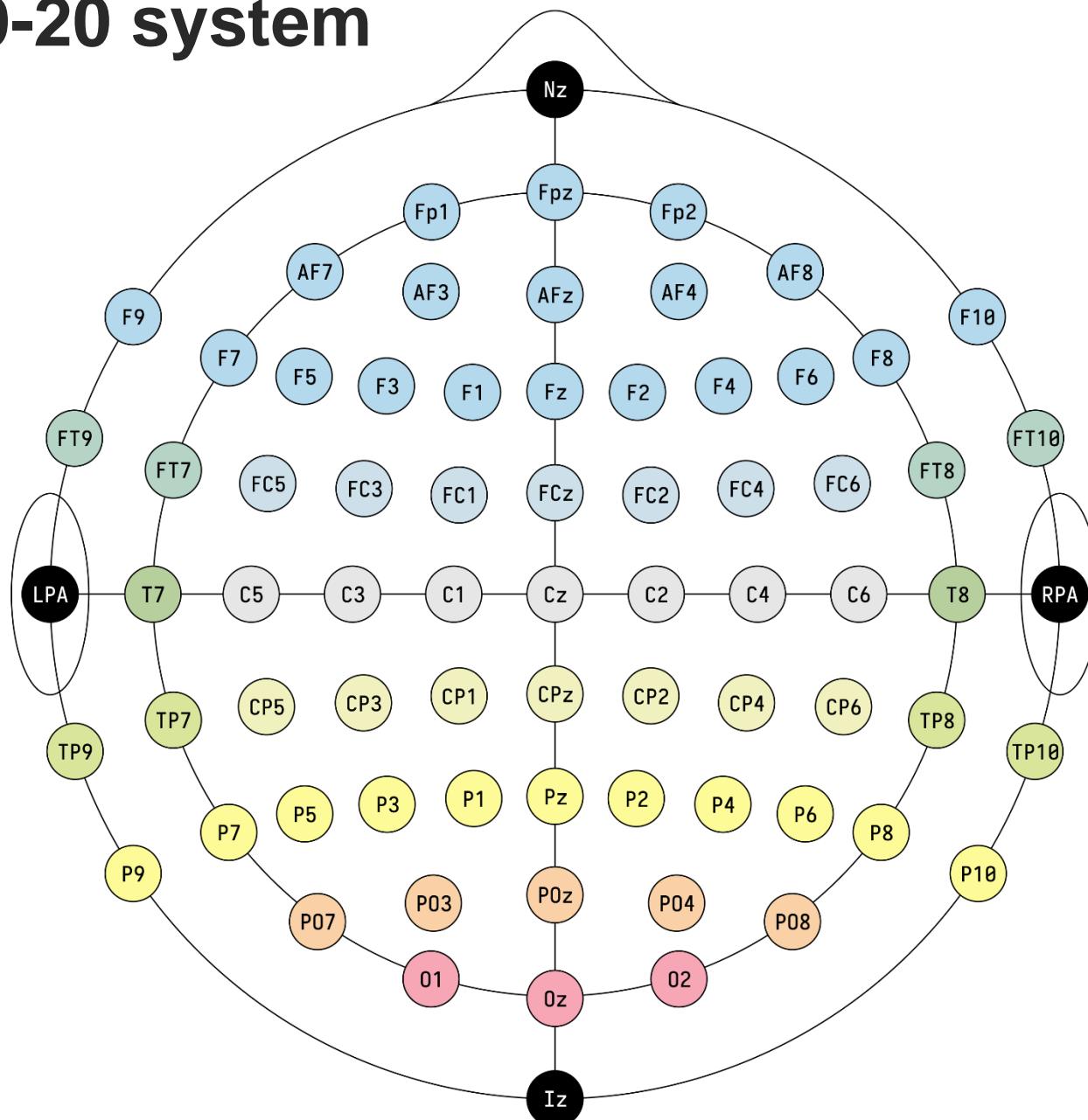


Figure by Irkrol is in the public domain

# Psychophysiology: Electrocortical measures: Recording

## Standardised caps

Fitted electrode caps make sure that the relative electrode positions are correct.

We have to make sure the cap is placed correctly!

Use the correct cap size, and place Cz on the centre of the head.



# Psychophysiology: Electrocortical measures: Recording

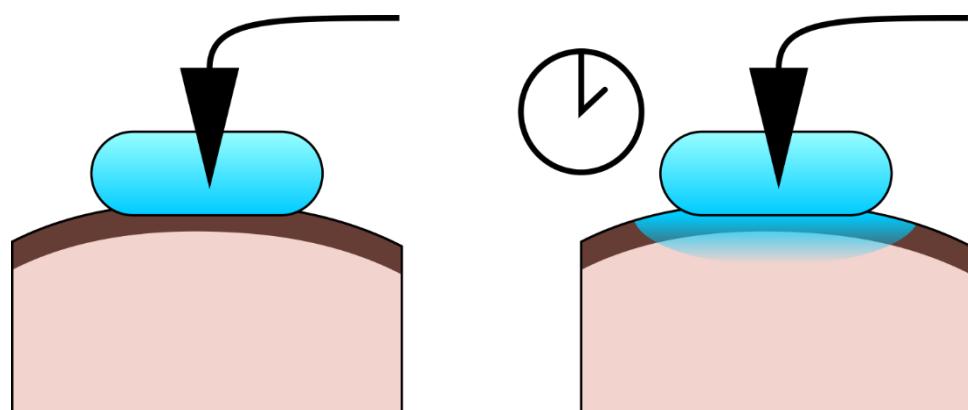
## Applying electrodes

To reduce impedance between the skin and the electrode and to make the connection more stable,

- the sites can be cleaned with alcohol, and/or
- the outer layer of dead skin cells can be abraded. Also,
- a conducting electrolyte gel is used.

The electrolyte diffuses into the skin over time, bridging over the outer layer.

It also provides stability against mechanical movement.



# Psychophysiology: Electrocortical measures: Recording

## Amplifier settings

For EEG, frequencies above 100 Hz are not commonly investigated. Following Nyquist, we may thus sample at 200 Hz.

To avoid aliasing, however, we generally record at five to ten times the highest frequency of interest, with a low-pass filter at half the sampling rate.

For a highest frequency of interest at 100 Hz, we may thus sample at 1000 Hz with a low-pass filter at 500 Hz.

# Psychophysiology: Electrocortical measures: Recording Artefacts

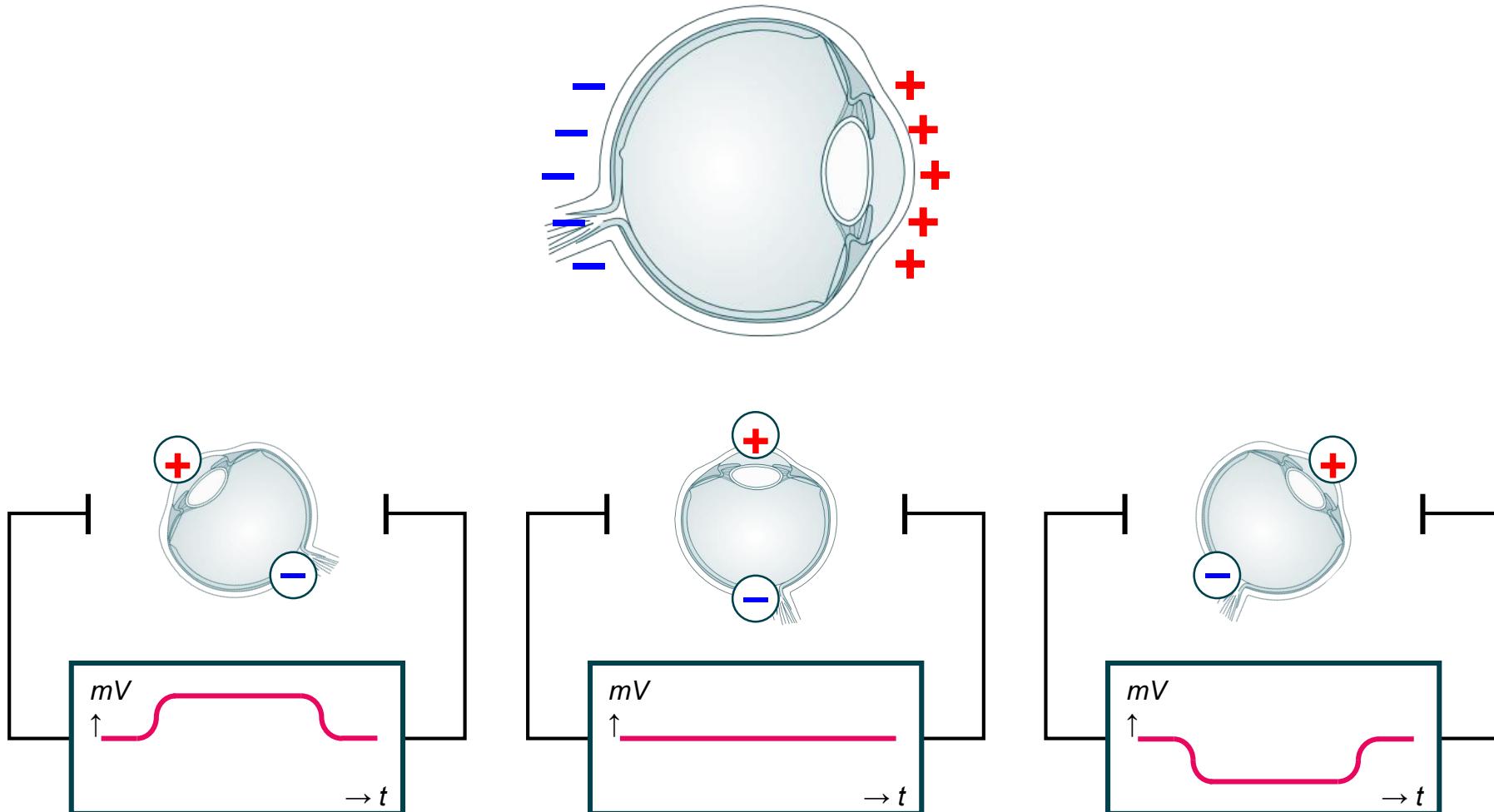
Aside from the general artefacts already discussed, e.g.

- environmental artefacts,
- mechanical artefacts,
- skin potentials, and
- muscle activity (face, neck, jaw),

**eye movements** are a prominent source of artefacts in EEG recordings.

# Psychophysiology: Electrocortical measures: Recording

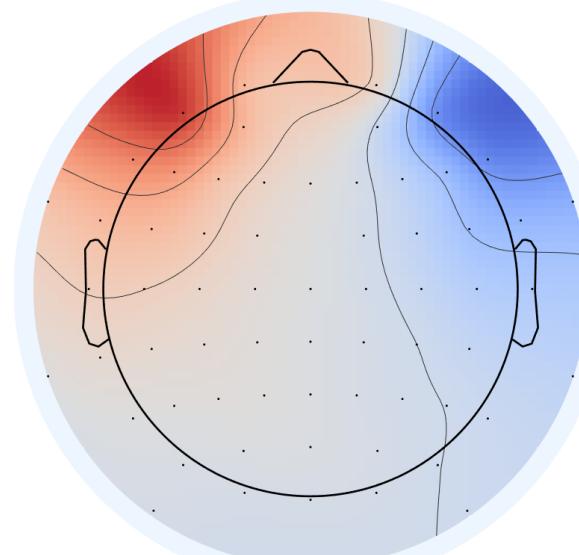
## Eye movements



# Psychophysiology: Electrocortical measures: Recording

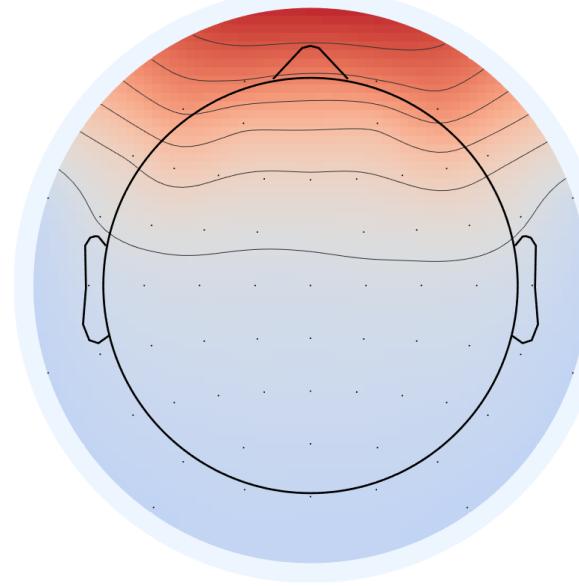
## Eye movements

During horizontal eye movements, the corneo-retinal dipole induces potential changes across the scalp.



Horizontal movement

Eye blinks, due to the eyelid “closing” the cornea-scalp circuit, similarly affect EEG recordings.



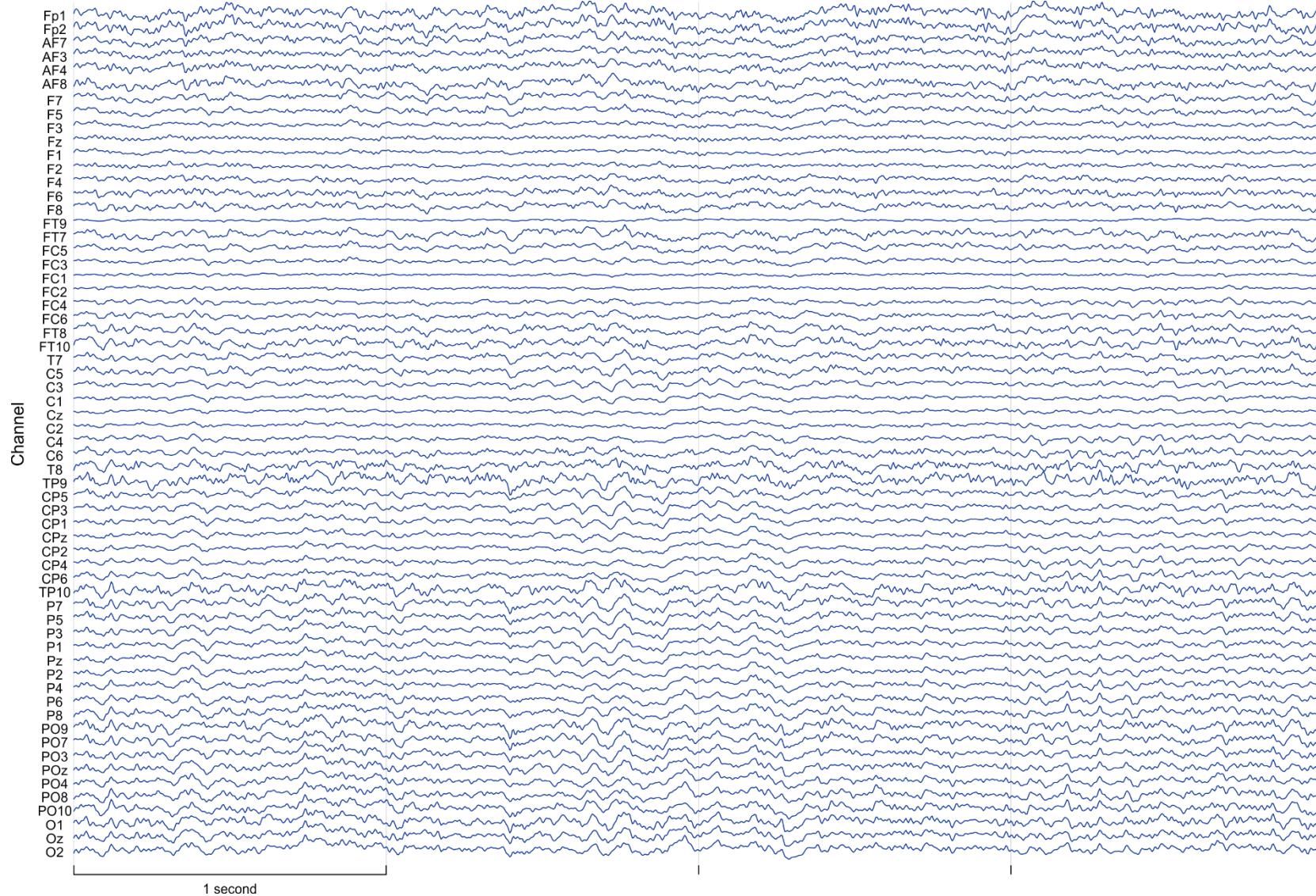
Blinks

# Psychophysiology: Electrocortical measures

## **Spontaneous EEG activity**

# Psychophysiology: Electrocortical measures

## The electroencephalogram



# Psychophysiology: Electrocortical measures

## Spontaneous EEG activity

“Spontaneous” brain activity refers to continuous ongoing brain activity that is present even in the absence of any discrete stimuli.

Essentially, our brains are always active: a living person’s EEG is never silent.

Different frequencies can be dissociated in this spontaneous EEG activity.

# Psychophysiology: Electrocortical measures

## Spontaneous EEG activity

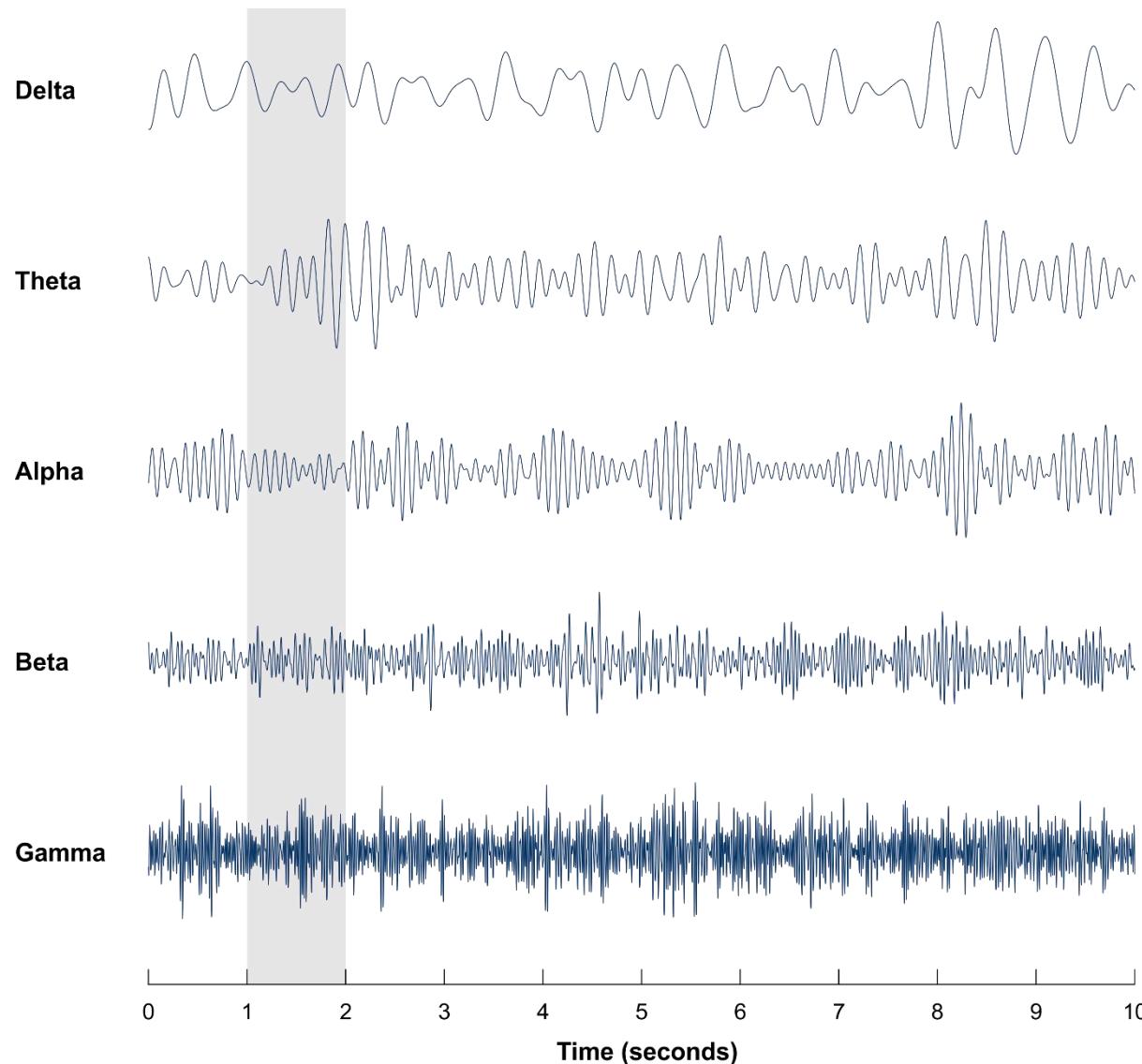
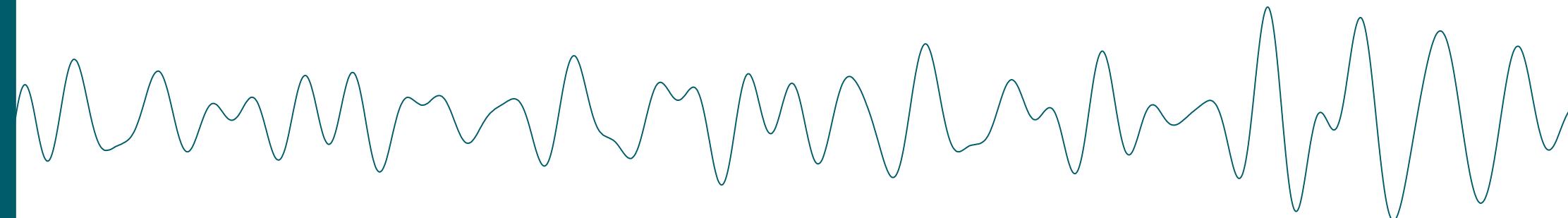


Figure by Irkrol is in the public domain

# Psychophysiology: Electrocortical measures: Spontaneous activity

## Delta rhythm (1-4 Hz)

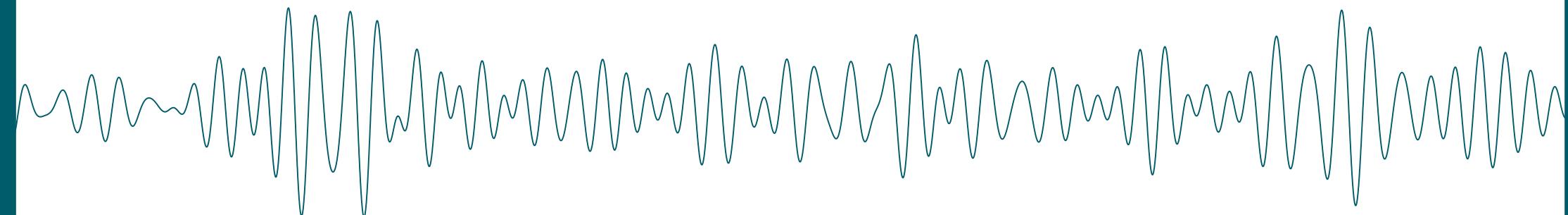
- Associated with phases of deep sleep, which are therefore also known as “slow-wave sleep” phases
- Associated with (induces) the release of a number of hormones
- No known cognitive or affective correlates



# Psychophysiology: Electrocortical measures: Spontaneous activity

## Theta rhythm (4-8 Hz)

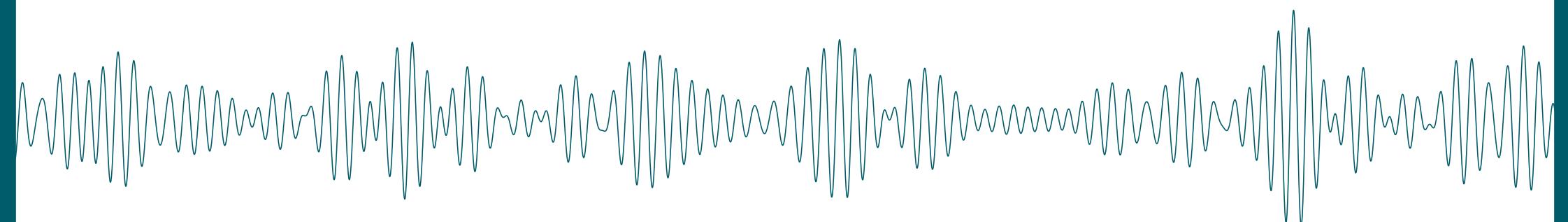
- Associated with transition phases from asleep to awake
- Associated with increased cognitive strain
- Associated with the processing of new information
- (Also associated with activity in the hippocampus, but this has little bearing on scalp EEG)



# Psychophysiology: Electrocortical measures: Spontaneous activity

## Alpha rhythm (8-12 Hz)

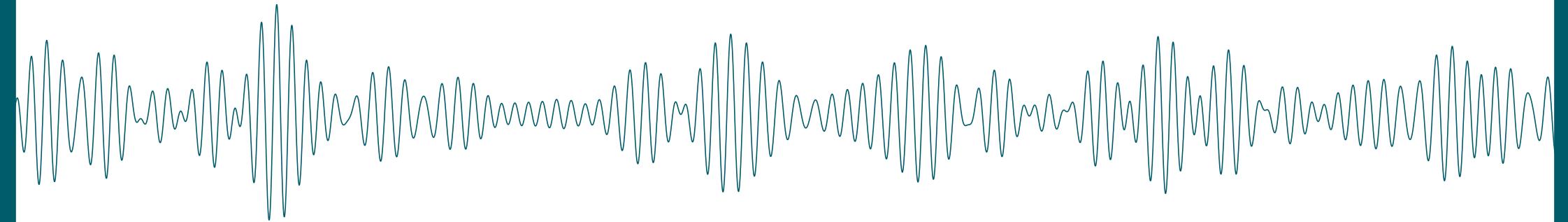
- Dominant regular frequency in human EEG (aside from bursts of delta activity)
- Most prominent during wakeful relaxation with closed eyes, primarily over occipital sites
- Alpha desynchronization (reduced alpha activity) is associated with attention and cognitive work, especially in combination with simultaneous theta synchronization (increased activity)



# Psychophysiology: Electrocortical measures: Spontaneous activity

## Mu (sensorimotor) rhythm (8-13 Hz)

- Similar to alpha, but distinguished from the alpha rhythm by location: the mu rhythm is associated with the motor cortex
- Mostly observed when no motor actions are performed



# Psychophysiology: Electrocortical measures: Spontaneous activity

## Beta rhythm (12-30 Hz)

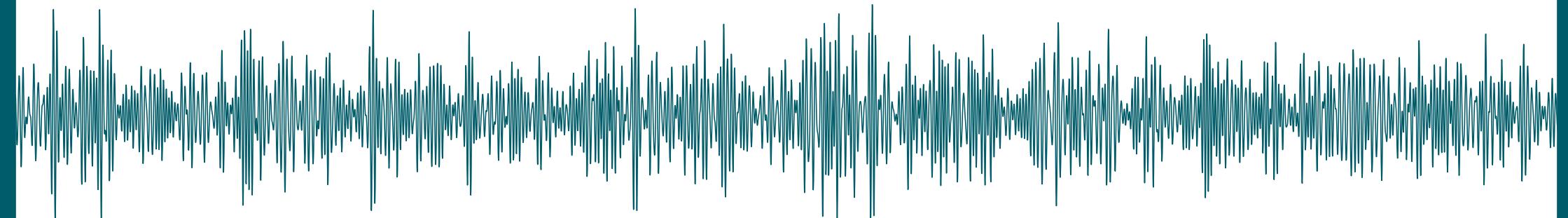
- Associated with mental and physical activity
- Often split into lower/higher ranges, e.g. at 20 Hz



# Psychophysiology: Electrocortical measures: Spontaneous activity

## Gamma rhythm (30+ Hz)

- Associated with attention and sensory processing
- Associated with integration and association of information across distributed networks
- “Prototypical” gamma is 40 Hz



# Psychophysiology: Electrocortical measures: Spontaneous activity

## Neural oscillations

The oscillatory nature of these various rhythms may reflect feedback loops in the brain, e.g. time-delayed connections between excitatory and inhibitory neurons.

Peak frequencies vary across persons. Frequency band definitions are largely historical and vary from field to field, time to time, expert to expert.

It is a gross simplification to simply equate activity of any frequency with any particular function.

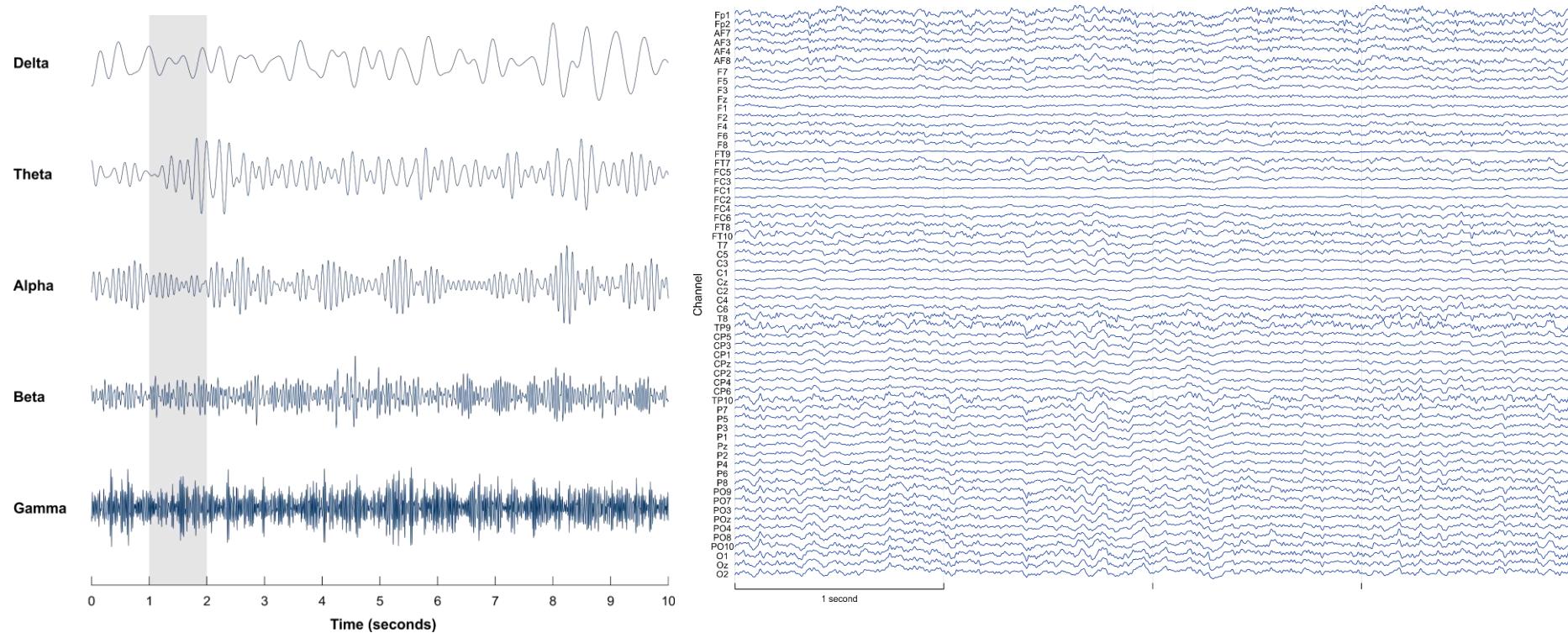


At the *very least*, take into account *where* in the brain the activity occurs, and *in what context*.

# Psychophysiology: Electrocortical measures: Spontaneous activity

# EEG contains activity of all frequencies

All frequency bands are always represented in EEG.



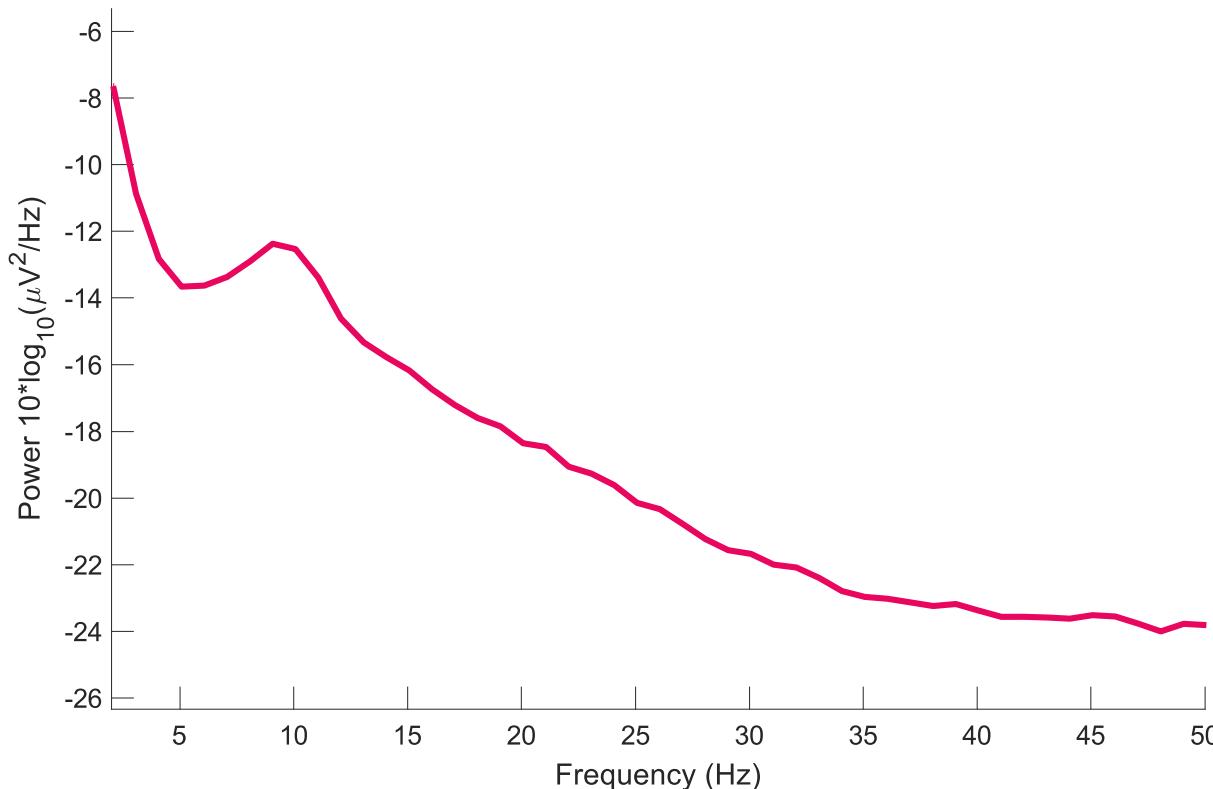
More generally, in fact, *any* signal can be decomposed into mixtures of different frequencies. (With EEG, some bands just have names.)

# Psychophysiology: Electrocortical measures

## Frequency domain analysis

# Psychophysiology: Electrocortical measures: Spectral Power spectrum

One way to analyse EEG is to look at its power spectrum, representing the power in all the different frequencies contributing to the recorded signal.



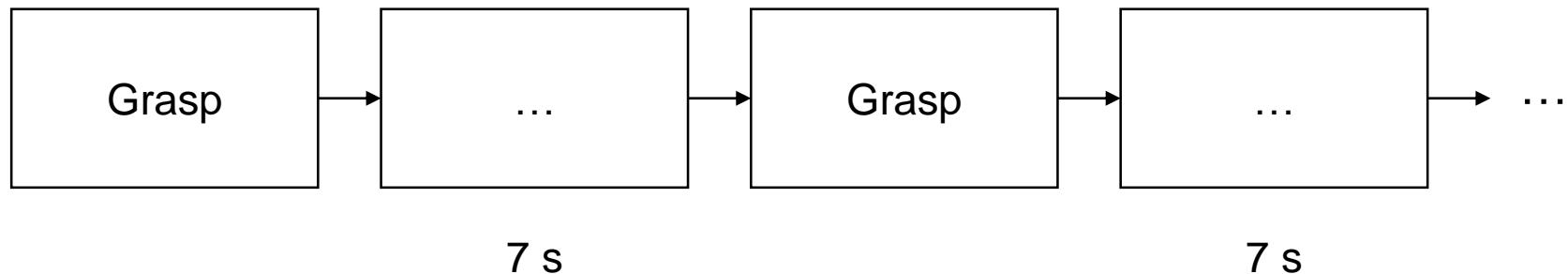
# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Mu-band desynchronisation

In different conditions, participants are asked to

- a) rest, or
- b) grasp an object

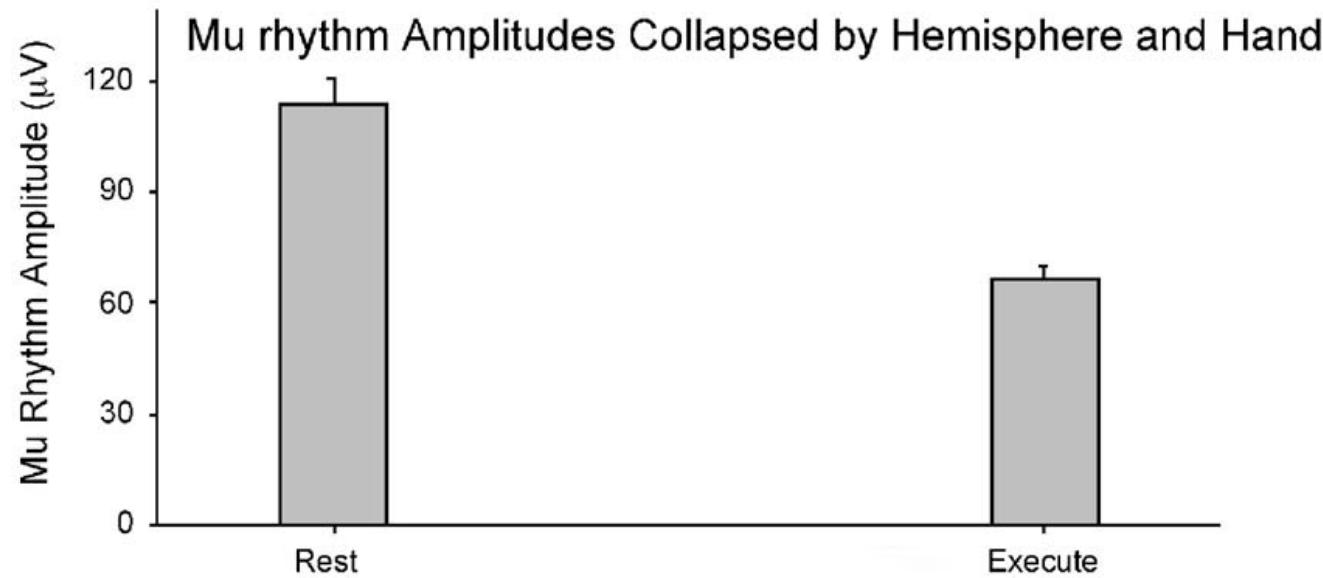
and repeat this multiple times with pauses in between.



# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Mu-band desynchronisation

Comparing power in the mu band over the motor cortex between conditions, we see:



# Psychophysiology: Electrocortical measures: Spectral

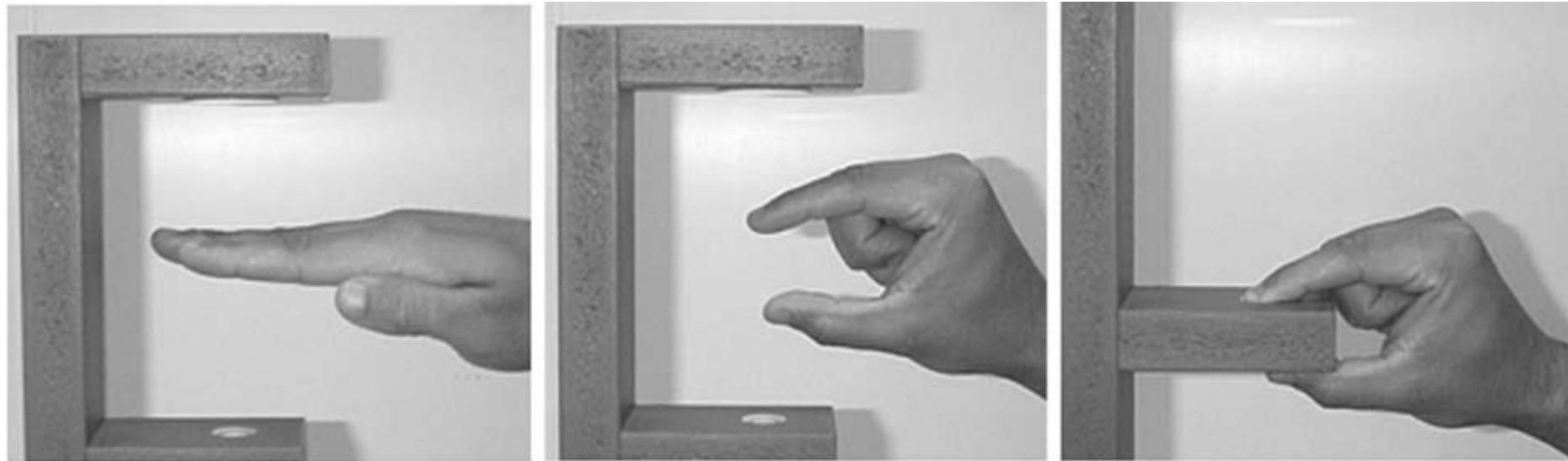
## Example experiment: Mu-band desynchronisation

The actual experiment had five conditions:

- a) rest;
- b) observe someone move their hand in a flat position;
- c) observe someone move their hand in a grasping motion;
- d) observe someone move their hand to grasp an object;
- e) grasp an object themselves.

# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Mu-band desynchronisation

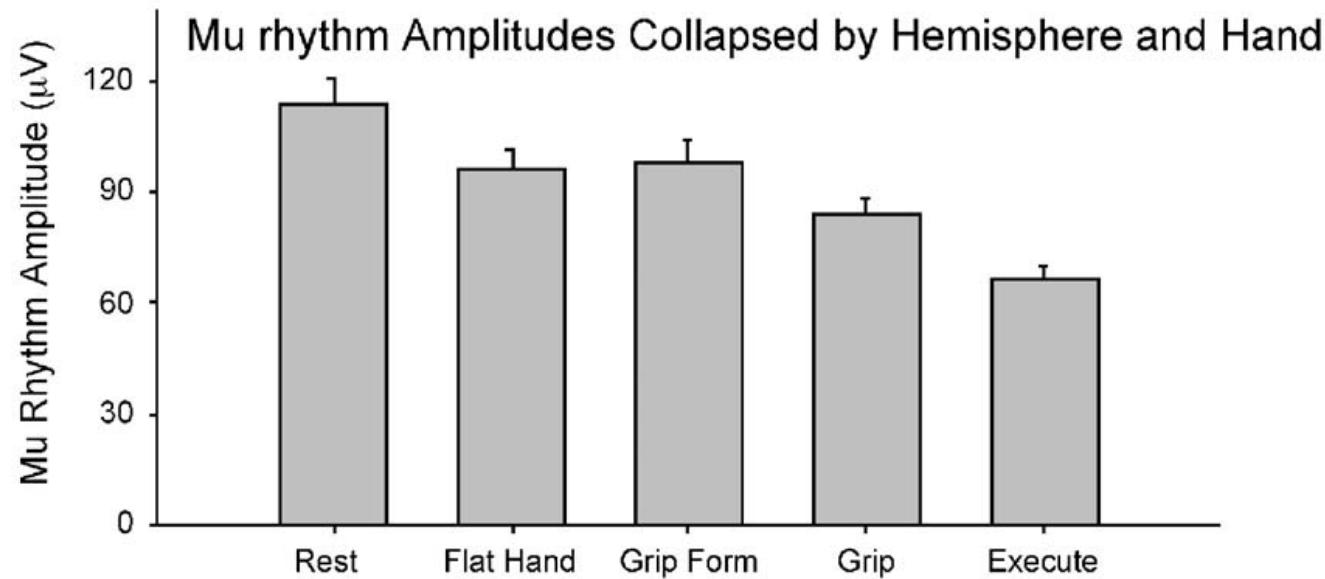


Muthukumaraswamy, S. D., Johnson, B. W., & McNair, N. A. (2004). Mu rhythm modulation during observation of an object-directed grasp. *Cognitive Brain Research*, 19(2), 195–201.

# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Mu-band desynchronisation

The mu rhythm responded to both observed and executed movements.

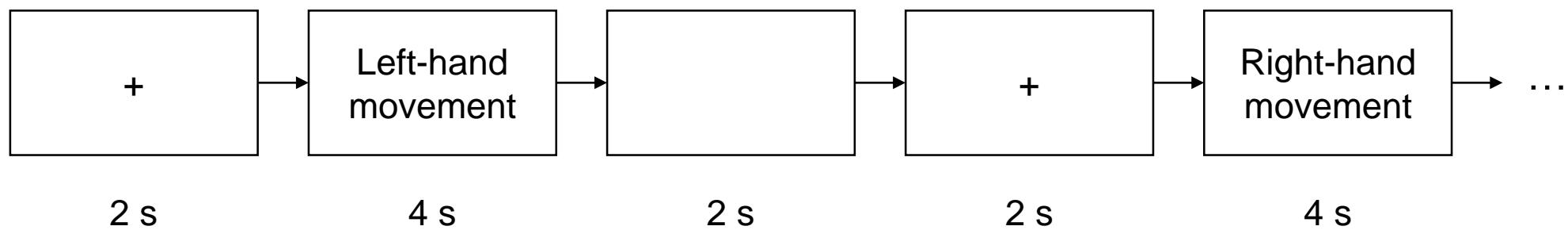


# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Motor imagery

The mu rhythm also responds to *imagined* movements.

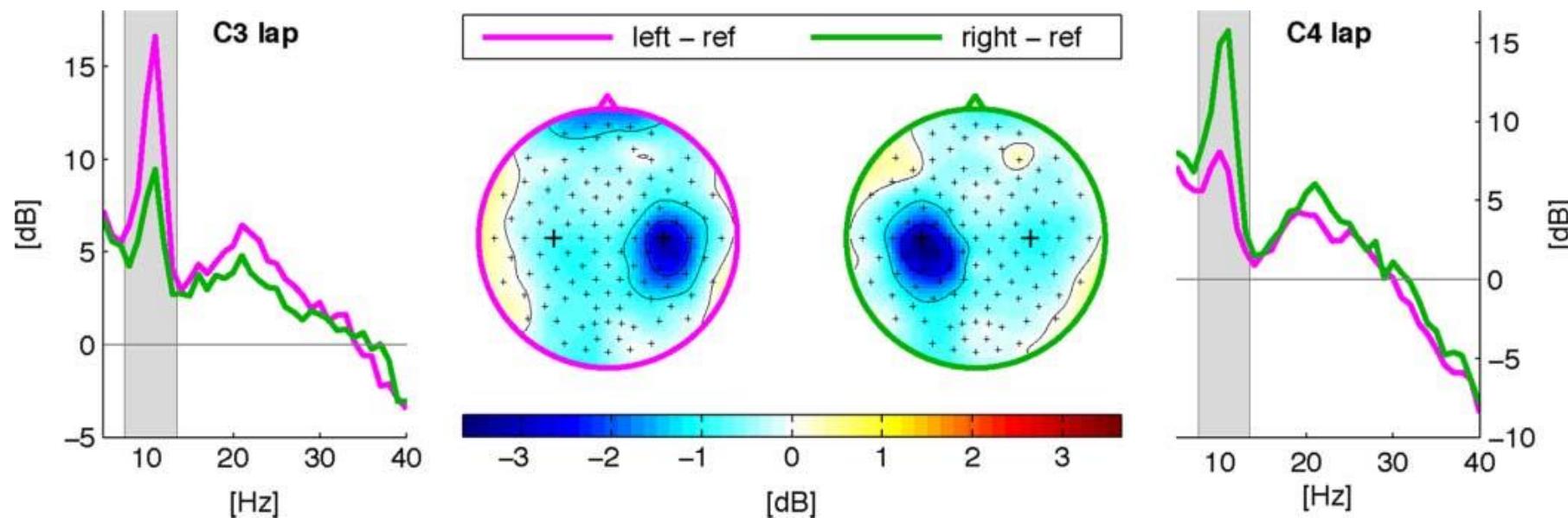
Motor imagery experiments generally ask participants to perform different kinds of imagined movement, e.g. different hands, feet, ...



# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Motor imagery

Different kinds of imagined movements produce different spatirospectral patterns in the EEG.



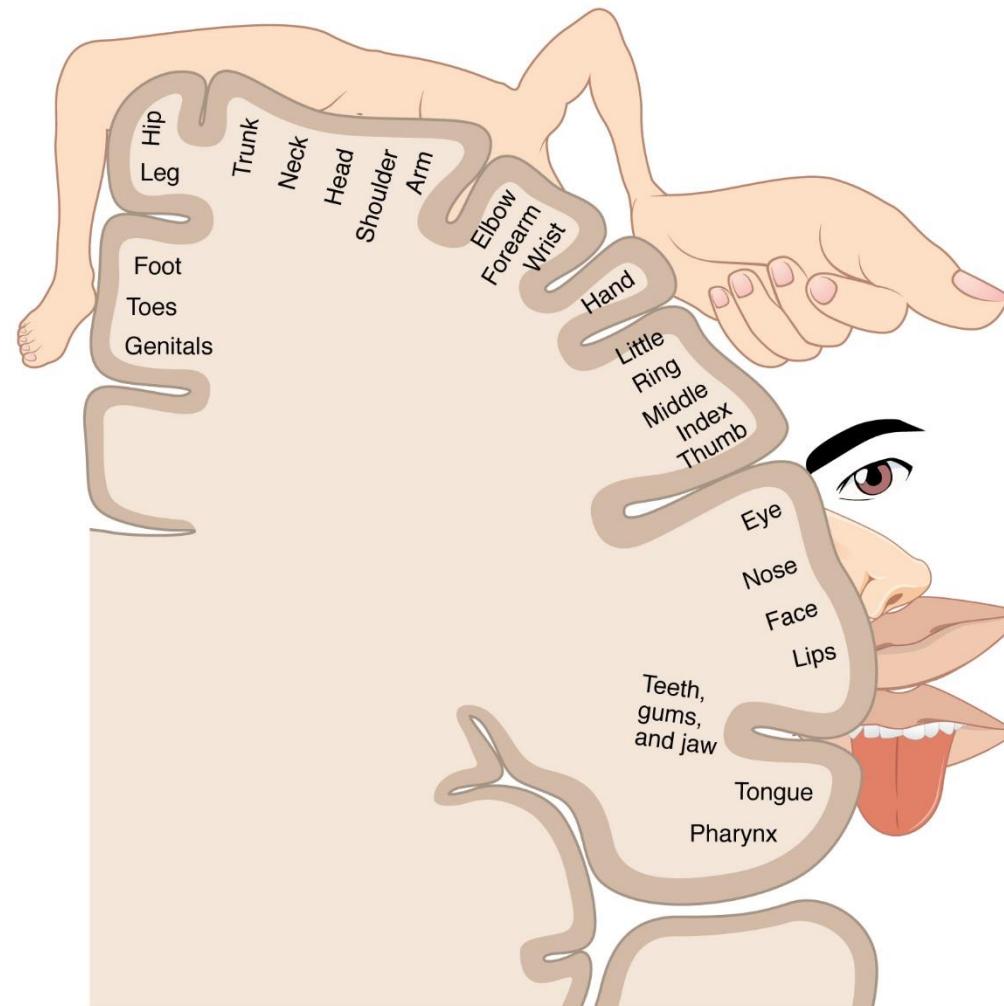
Maeder, C. L., Sannelli, C., Haufe, S., & Blankertz, B. (2012). Pre-stimulus sensorimotor rhythms influence brain–computer interface classification performance. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 20(5), 653–662.

# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Motor imagery

The motor cortex is organised as a topographic map of the body.

This organisation is *contralateral*.



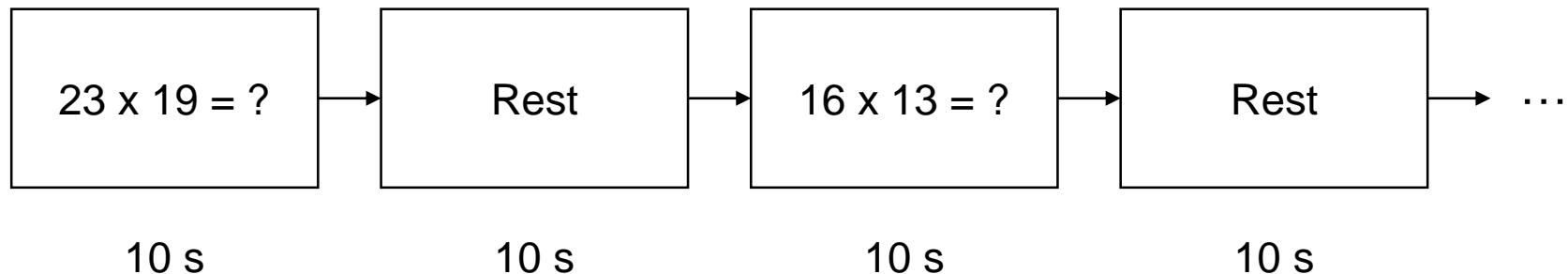
# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Workload

Participants are asked to

- a) rest
- b) perform a mentally straining task (e.g. arithmetic)

for a few seconds each, and then repeat.



# Psychophysiology: Electrocortical measures: Spectral

## Example experiment: Workload

Workload is commonly found to produce a *parietal decrease* in alpha-band activity with a simultaneous *frontal increase* in theta-band activity.

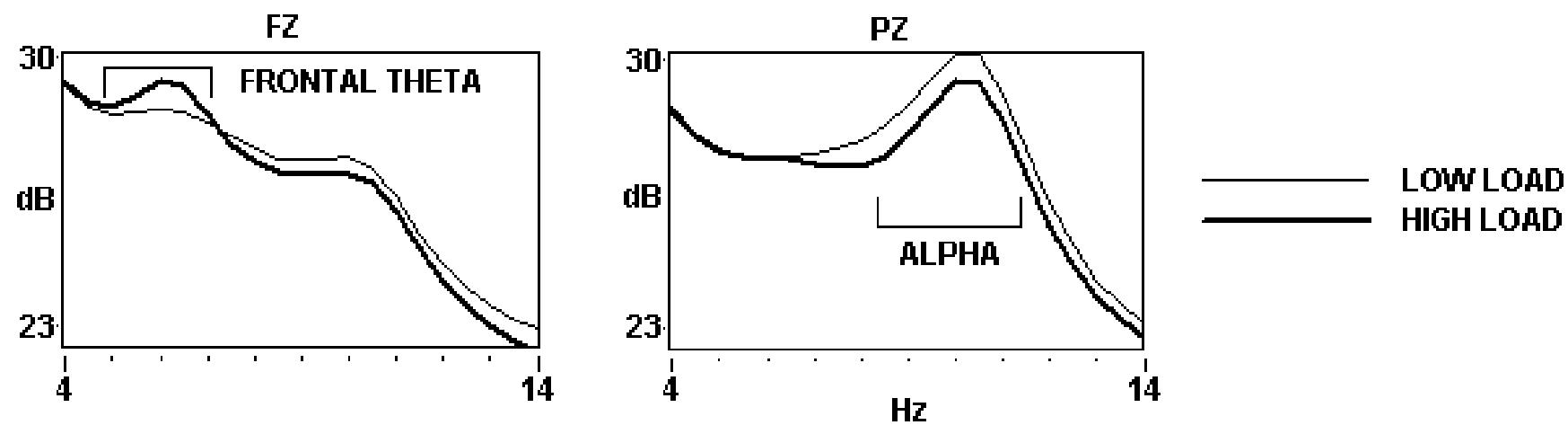


Figure: Gevins, A., & Smith, M. E. (2003). Neurophysiological measures of cognitive workload during human-computer interaction. *Theoretical Issues in Ergonomics Science*, 4(1-2), 113–131.

# Psychophysiology: Electrocortical measures

## Frequency domain analysis

Comparing EEG activity between different conditions, we can find differences in the spectral power of different frequency bands.

We can look at multiple frequency bands at the same time, as well the spatial patterns of different frequency bands, to obtain more specific results.

As such, we can for example differentiate between different types of imagined movement, and phases of high and low mental load.

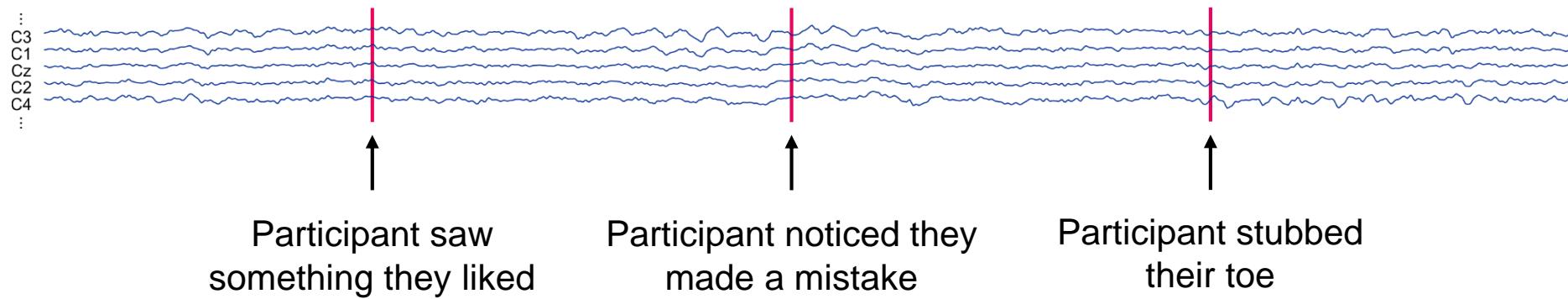
# Psychophysiology: Electrocortical measures

## Time domain analysis

# Psychophysiology: Electrocortical measures

## Event-related analysis

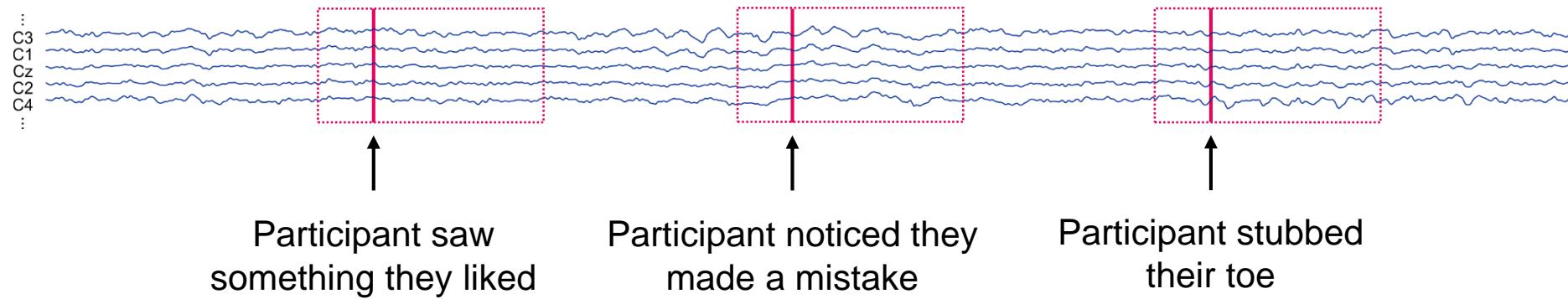
Rather than brain activity generalized across conditions, can we detect changes in brain activity in response to specific events?



# Psychophysiology: Electrocortical measures: Temporal

## The event-related potential (ERP)

A segment of EEG activity investigated relative to a specific event is called an event-related potential.



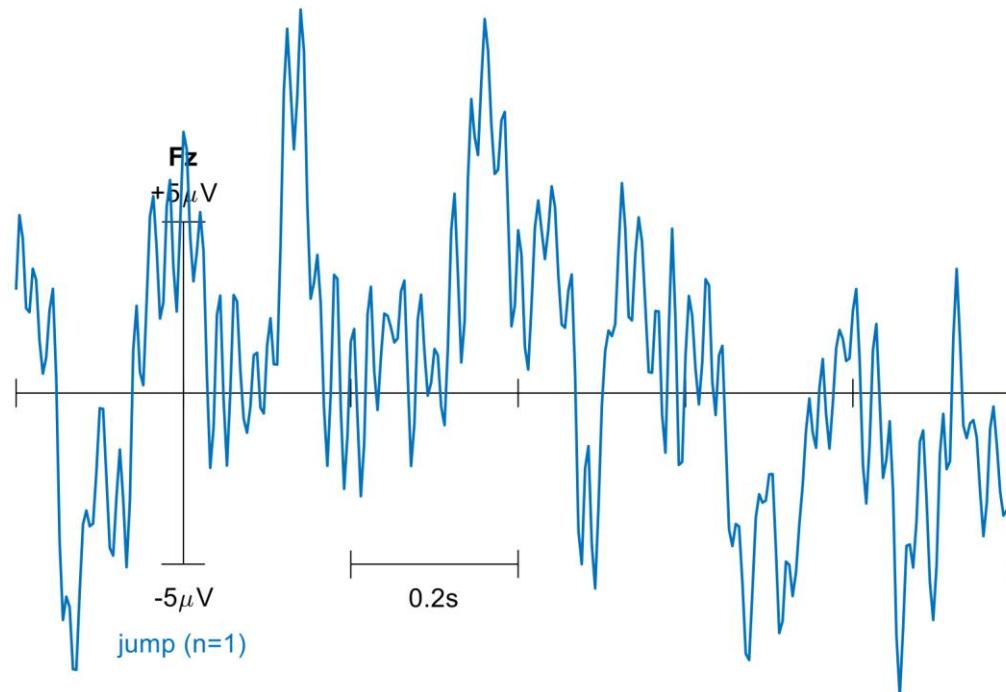
Participant saw  
something they liked

Participant noticed they  
made a mistake

Participant stubbed  
their toe

# Psychophysiology: Electrocortical measures: Temporal Epoching and ERP averaging

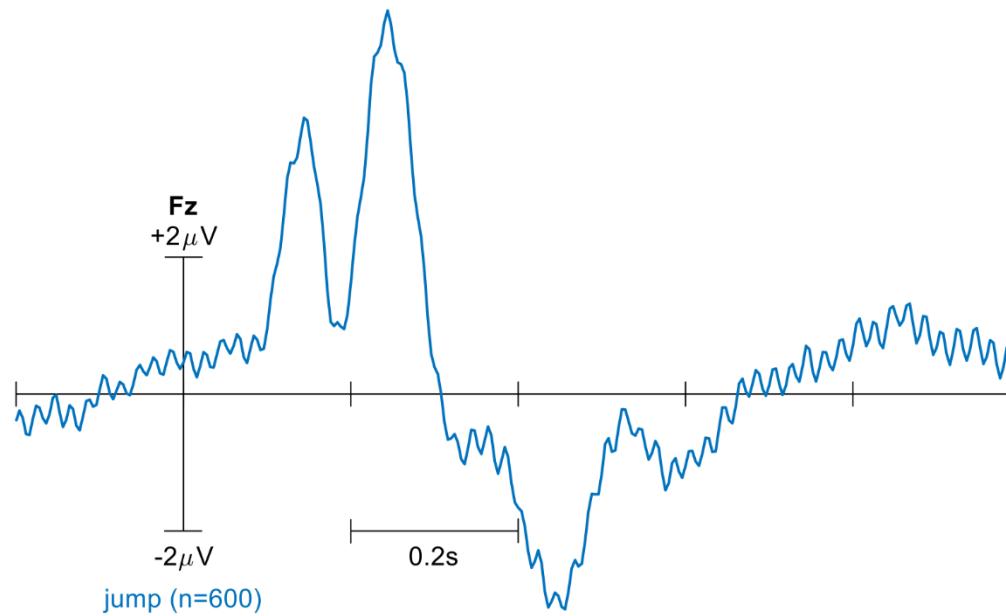
Looking at one such ERP, you will probably find nothing.



This is because there is too much other (brain) activity going on that is not related to the event.

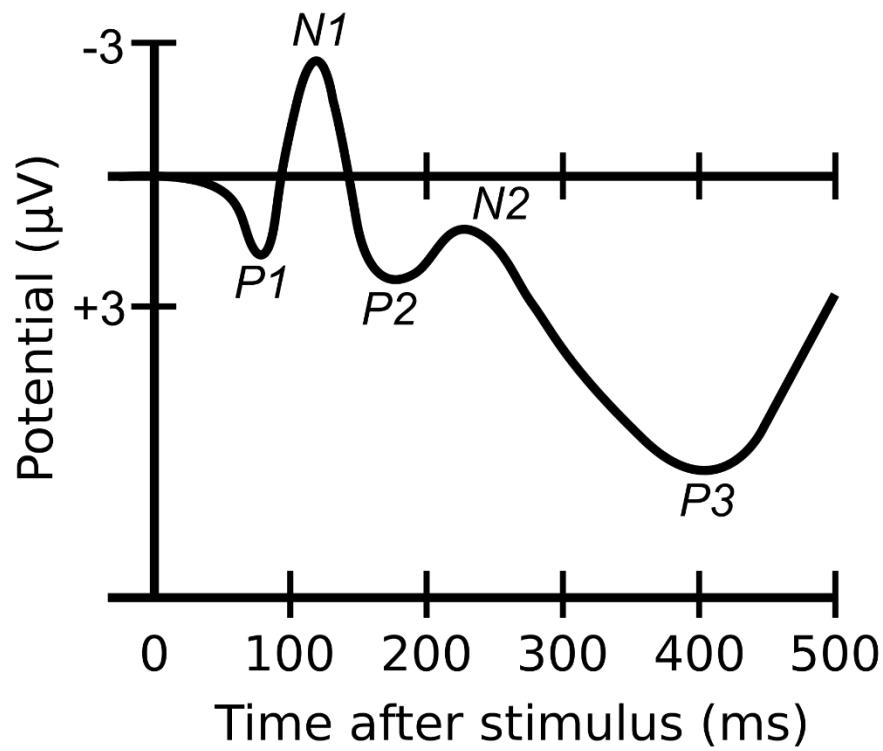
# Psychophysiology: Electrocortical measures: Temporal Epoching and ERP averaging

Epoching is the practice of extracting all time segments relative to specific events from an EEG recording.



When you take the average ERP across multiple epochs, activity that does not systematically vary relative to the event and a specific baseline is averaged out.

# Psychophysiology: Electrocortical measures: Temporal ERP components



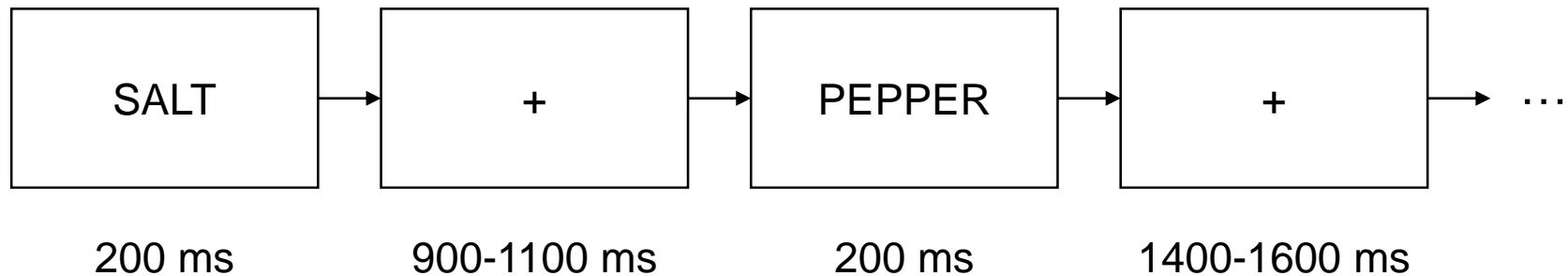
# Psychophysiology: Electrocortical measures: Temporal

## Example experiment: Word semantics

Participants are shown one word. The next word is either

- a) related to the first word, or
- b) unrelated to the first word.

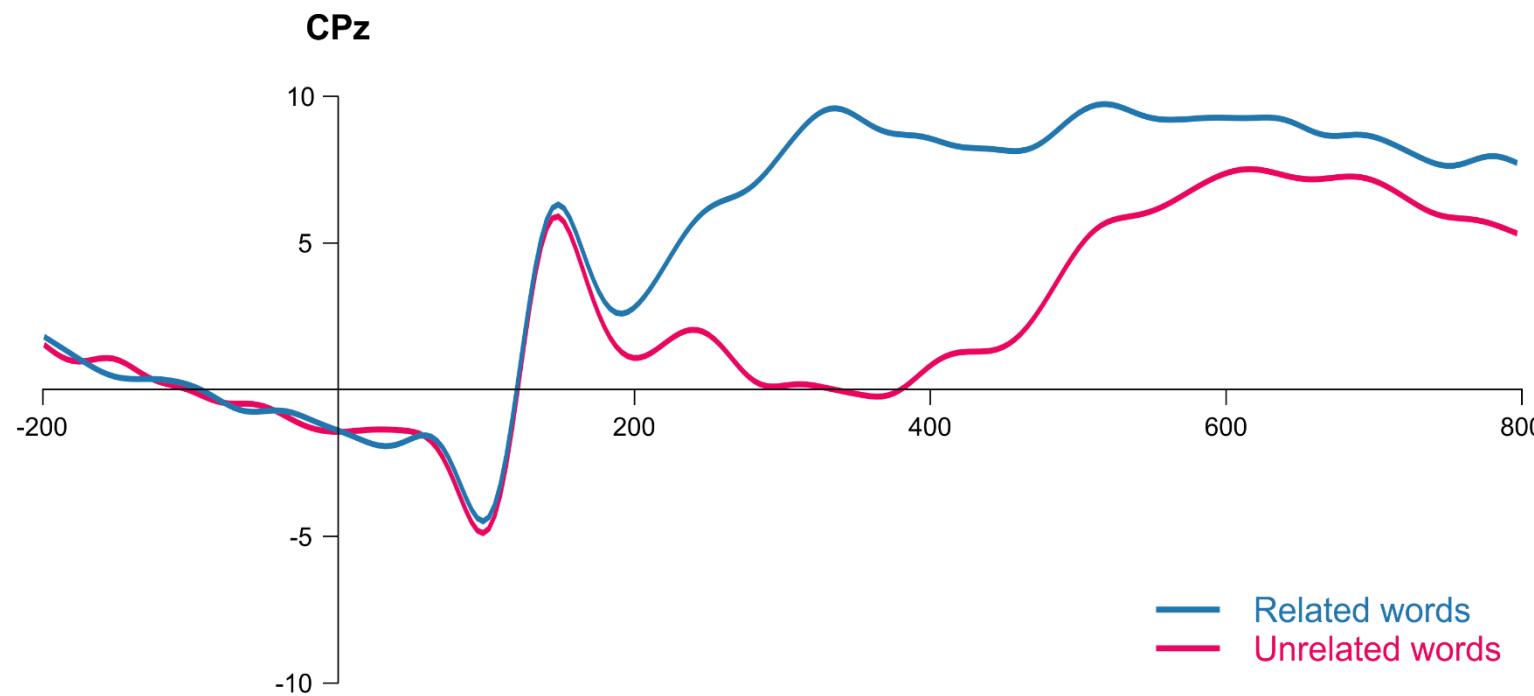
This is repeated for many word pairs.



# Psychophysiology: Electrocortical measures: Temporal

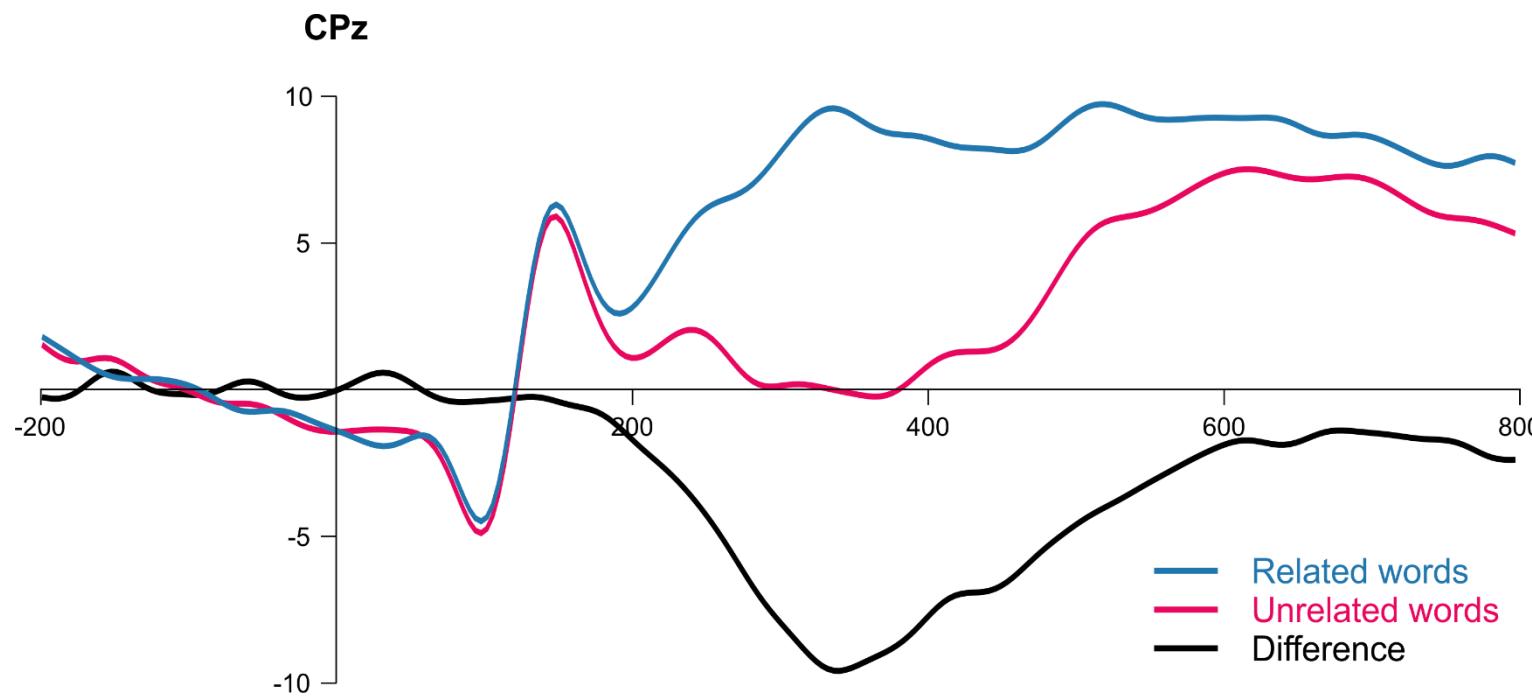
## Example experiment: Word semantics

Comparing the event-related potential for relevant and non-relevant words, we see:



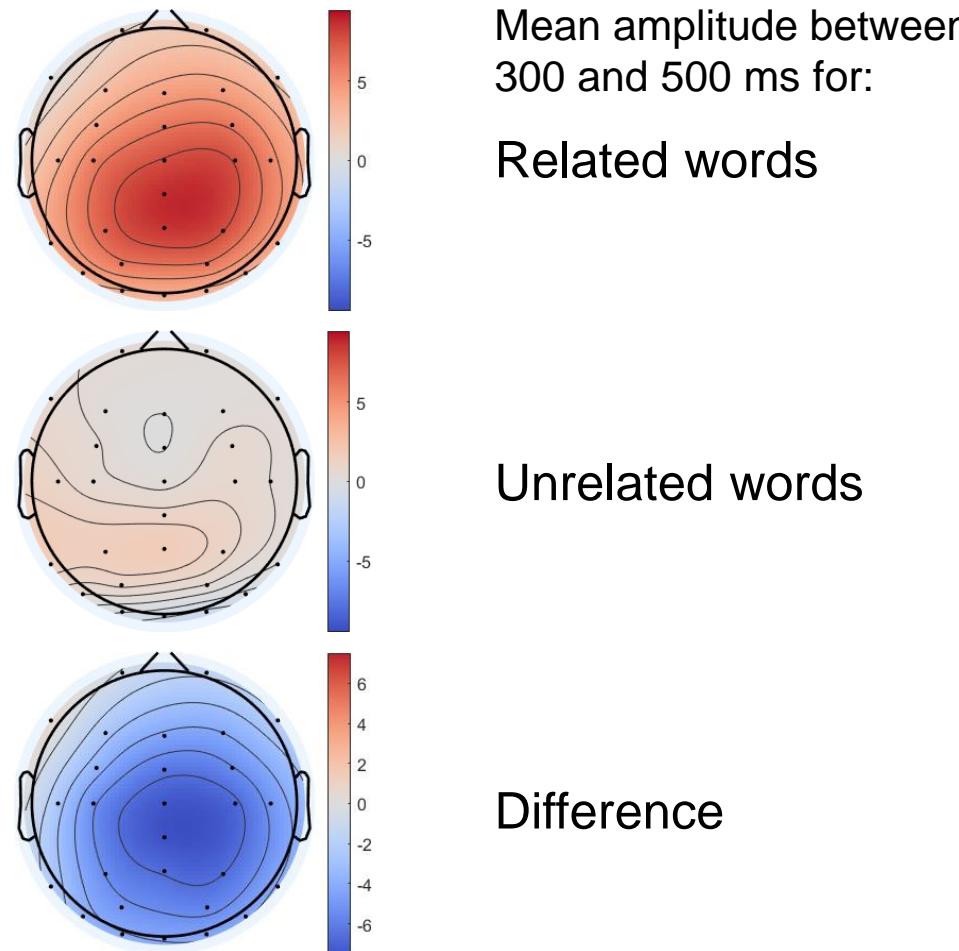
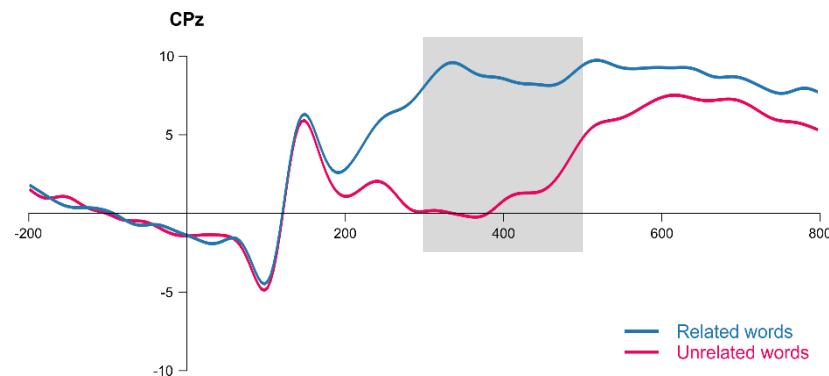
# Psychophysiology: Electrocortical measures: Temporal Difference wave

To focus on the differences between conditions, subtract one ERP's amplitude from the other's at each time sample.



# Psychophysiology: Electrocortical measures: Temporal Spatial analysis of ERPs

By topographically mapping each channel's ERP amplitude, it can also be analysed spatially.

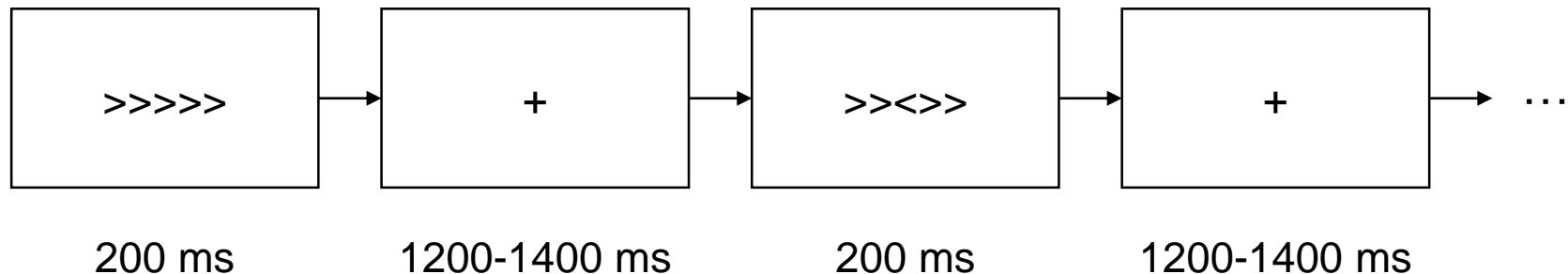


# Psychophysiology: Electrocortical measures: Temporal

## Example experiment: Flanker test

Participants are shown a string of “<”s and “>”s. As quickly as possible, they have to indicate what direction the *middle* character is pointing. The surrounding “flankers” either

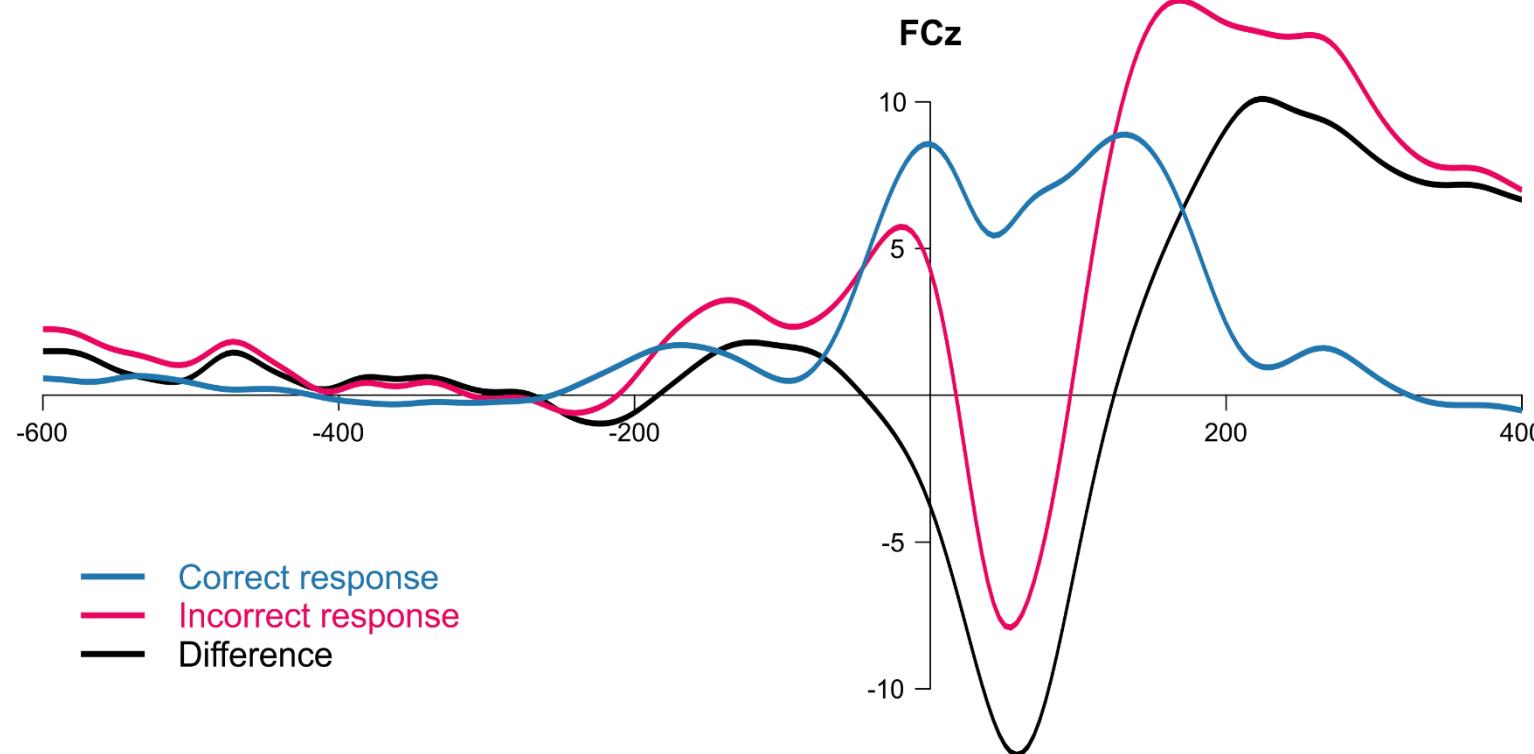
- a) point in the same direction (congruent: easy), or
- b) point in the other direction (incongruent: confusing).



# Psychophysiology: Electrocortical measures: Temporal

## Example experiment: Flanker test

Comparing the event-related potential following correct versus incorrect responses, we see:

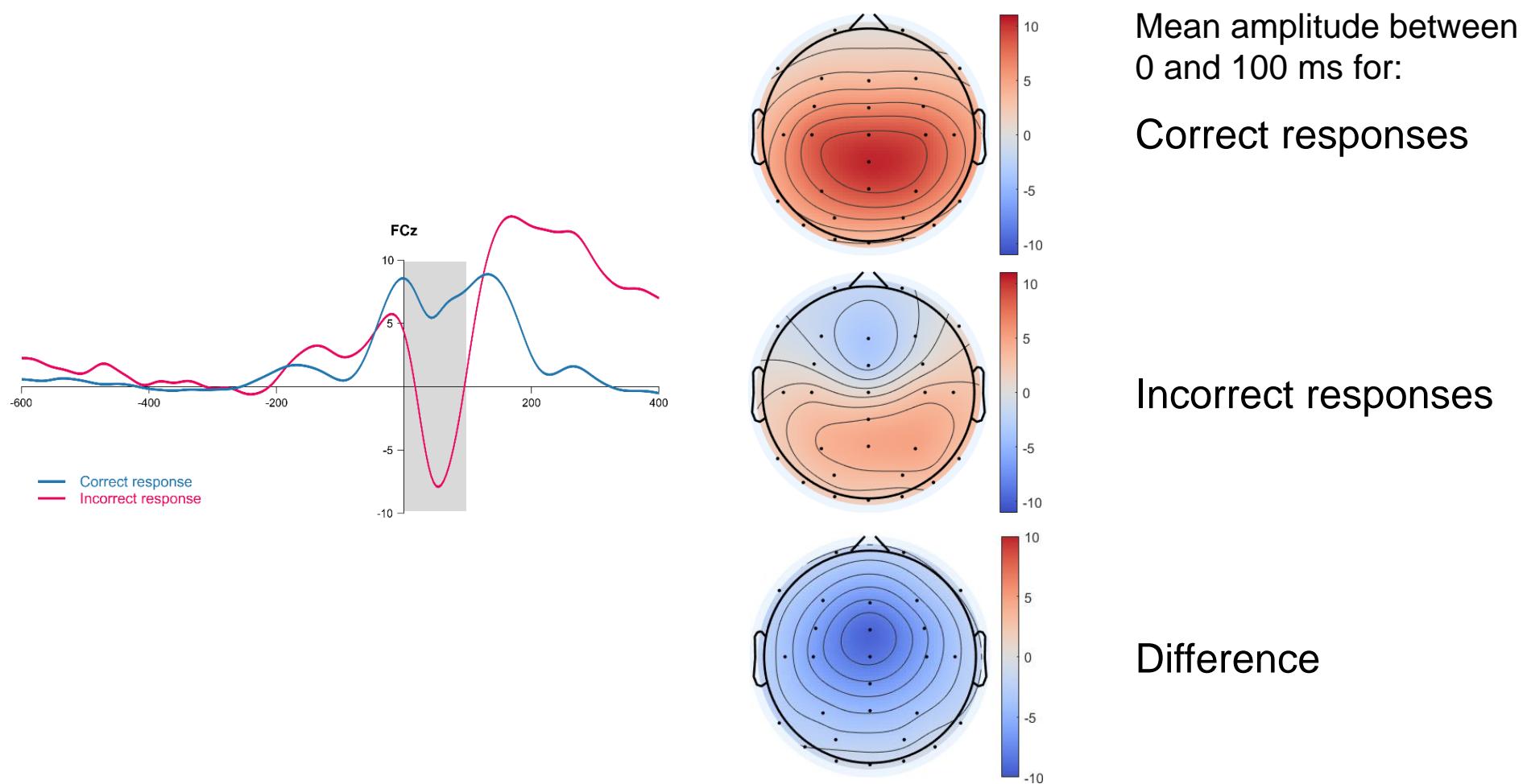


Data from: Kappenman, E. S., Farrens, J. L., Zhang, W., Stewart, A. X., & Luck, S. J. (2021). ERP CORE: An open resource for human event-related potential research. *NeuroImage*, 225, 117465.

# Psychophysiology: Electrocortical measures: Temporal

## Example experiment: Flanker test

The differential activity projects primarily onto frontal sites.



Data from: Kappenman, E. S., Farrens, J. L., Zhang, W., Stewart, A. X., & Luck, S. J. (2021). ERP CORE: An open resource for human event-related potential research. *NeuroImage*, 225, 117465.

# Psychophysiology: Electrocortical measures

## Time domain analysis

The main time domain analysis method is the event-related potential technique.

Multiple instances of brain activity relative to the same event are averaged together. This leaves systematic event-related changes, while averaging out irrelevant noise.

Comparing ERPs across conditions, detailed differences can be found.

# Psychophysiology: Electrocortical measures

## Time-frequency analysis

# Psychophysiology: Electrocortical measures

## Time-frequency analysis

Estimates of band power can also be calculated for smaller periods of time, e.g. using *wavelet transform*.

This allows spectral properties to be analysed over time.

# Psychophysiology: Electrocortical measures: Spectrotemporal

## Example experiment: Go/NoGo button press

Participants attended to one coloured square out of five. They pressed a button when a stimulus appeared in the attended square.

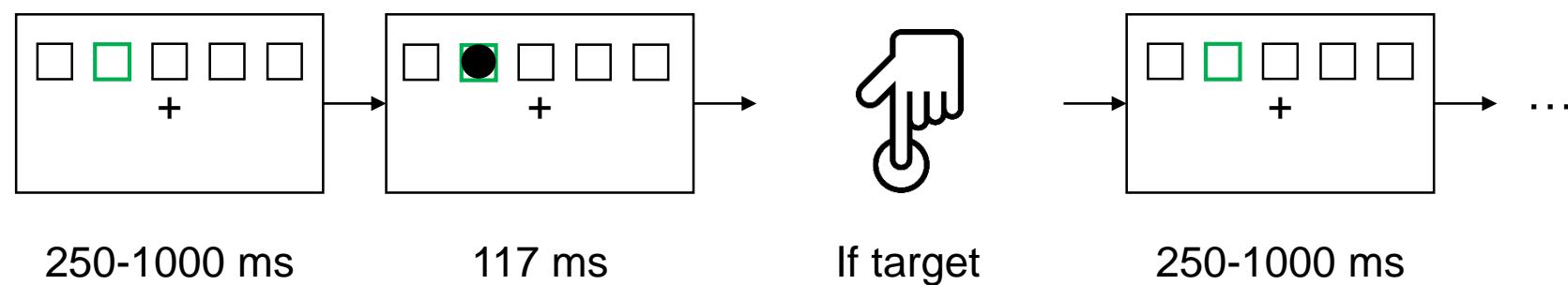


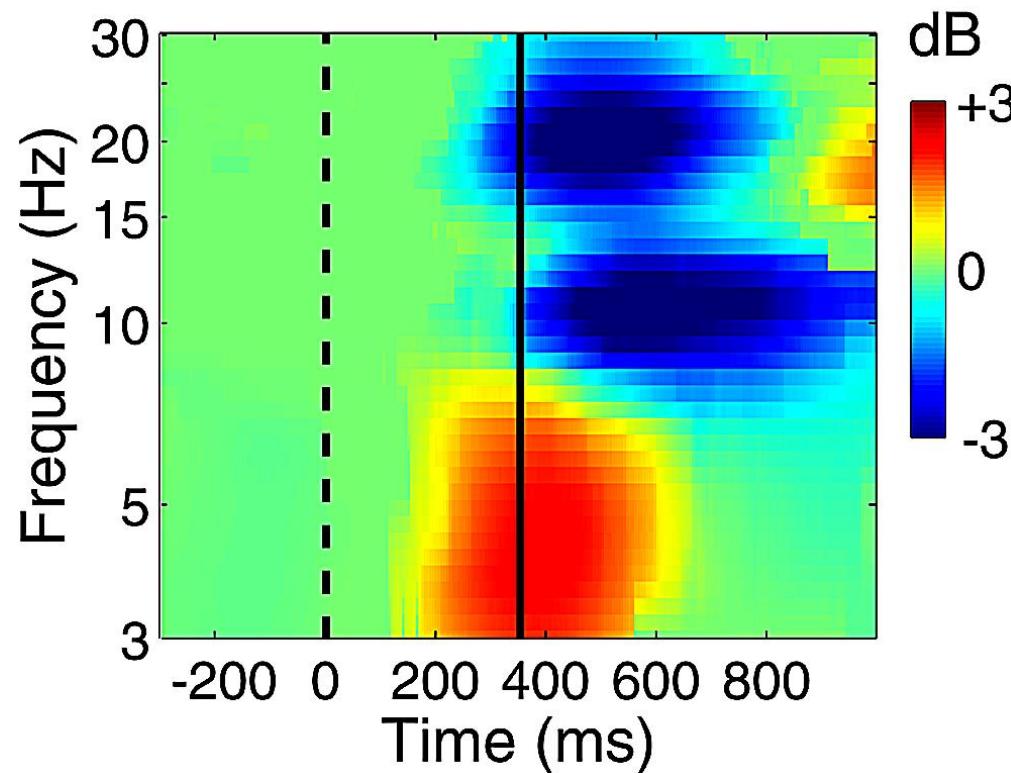
Figure “press button” by Hea Poh Lin is licensed under CC BY 3.0 via Noun Project

Makeig, S., Delorme, A., Westerfield, M., Jung, T.-P., Townsend, J., Courchesne, E., & Sejnowski, T. J. (2004). Electroencephalographic brain dynamics following manually responded visual targets. *PLOS Biology*, 2(6), 0747–0762.

# Psychophysiology: Electrocortical measures: Spectrot temporal

## Event-related spectral perturbation (ERSP)

The ERSP shows the changes in power relative to a baseline time-locked to the manual response.



# Psychophysiology: Electrocortical measures

## Time-time analysis

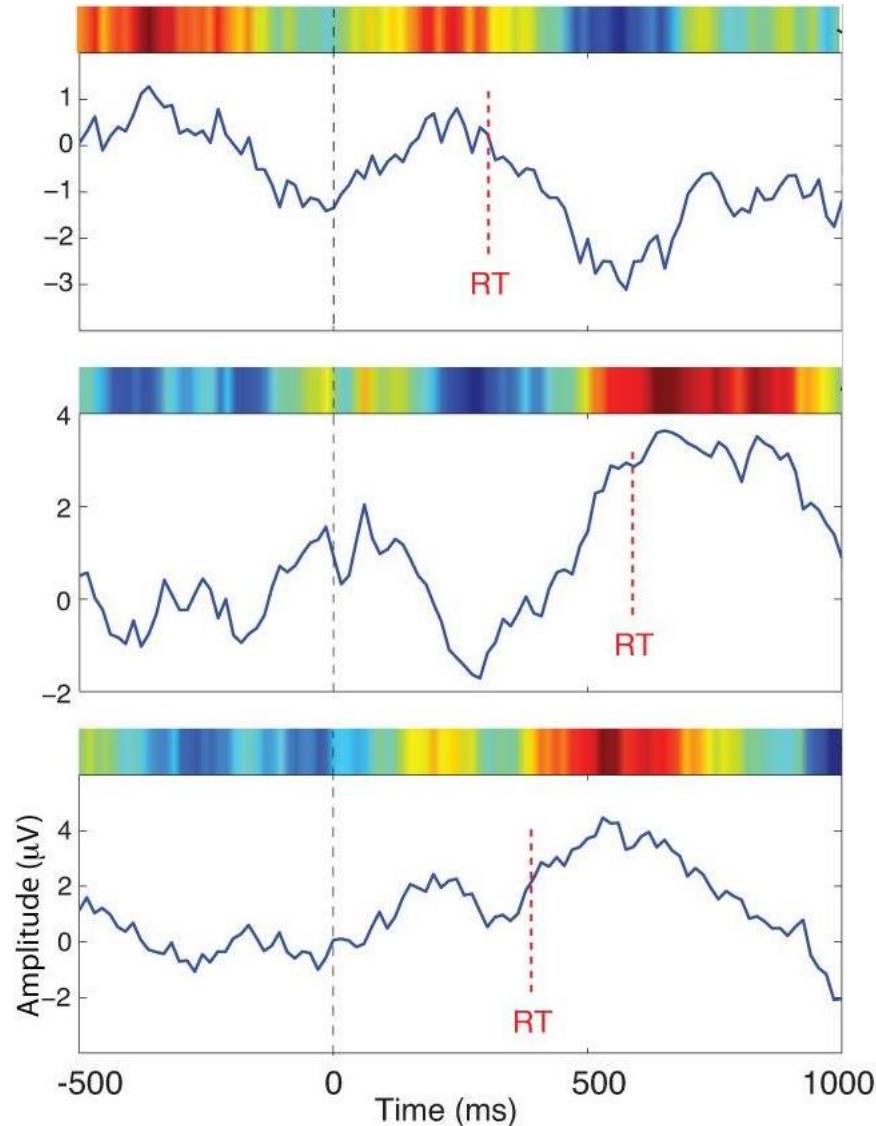
# Psychophysiology: Electrocortical measures

## Time-time analysis

The event-related potential is often investigated as an average across many trials.

The *ERP image* shows multiple single-trial ERPs across time.

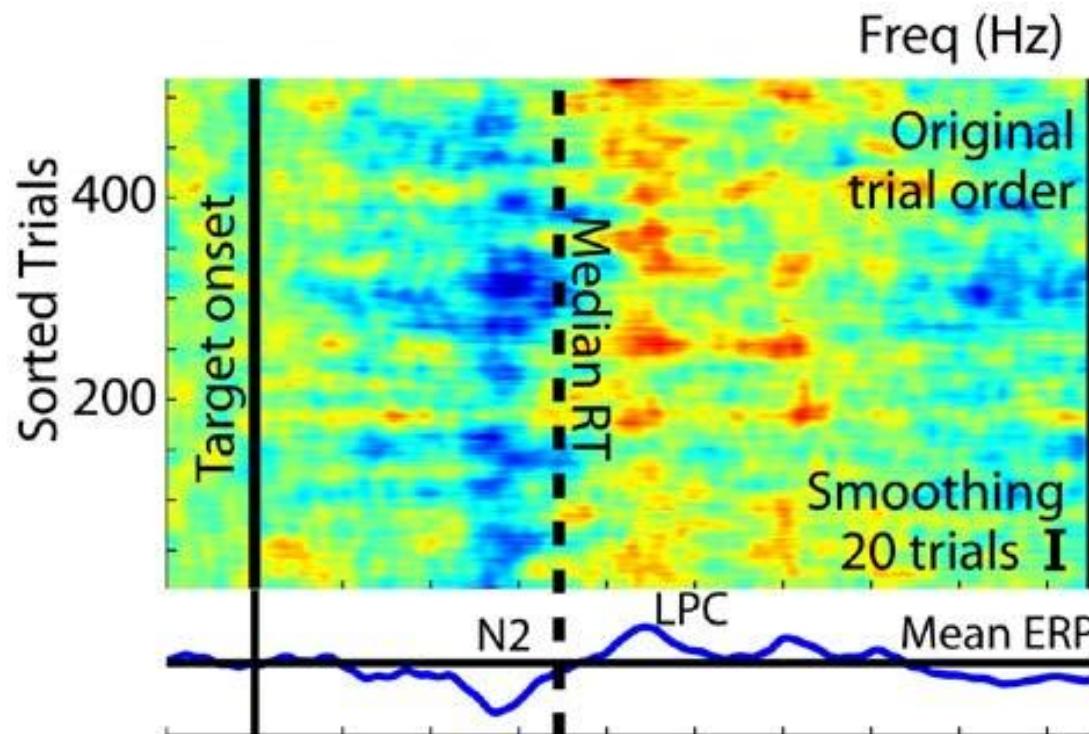
First, the single-trial ERP amplitudes are colour-coded.



# Psychophysiology: Electrocortical measures: Temporotemporal

## Time-time analysis

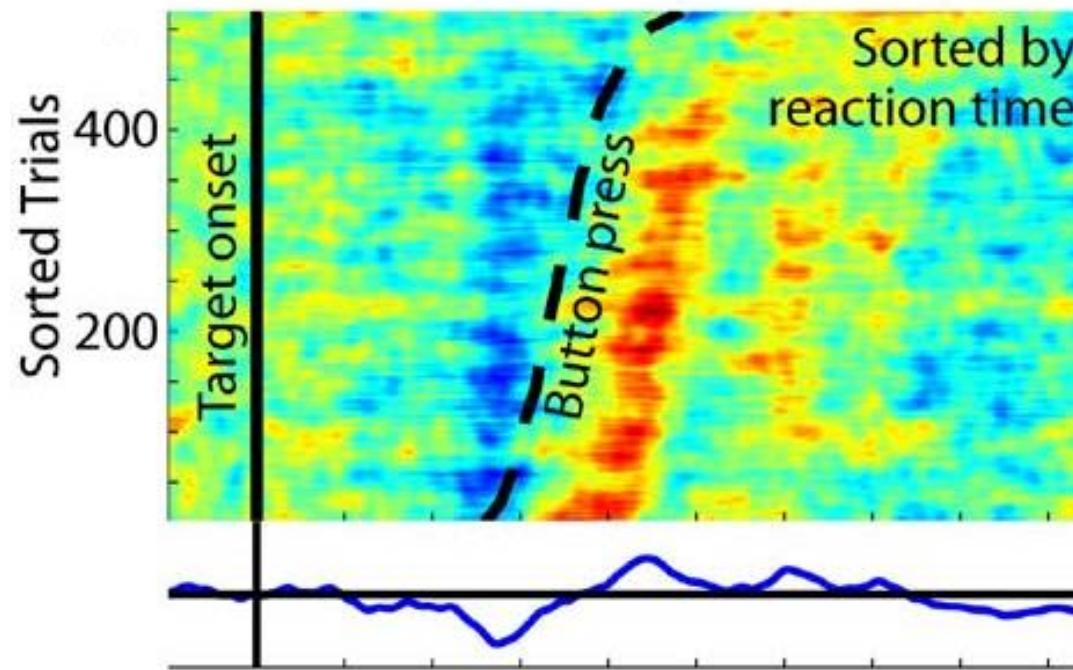
Stacking multiple colour-coded single-trial ERPs creates an ERP image.



# Psychophysiology: Electrocortical measures: Temporotemporal

## Time-time analysis

By vertically re-sorting the trials, here by reaction time, different ERP effects become clearly visible.



# Psychophysiology

## Electrocortical measures

The three spectral, temporal, and spatial domains—and combinations thereof—are all relevant to the analysis of EEG activity.

Analysis can be performed between conditions, or relative to specific events.

Averages of many trials cancel out noise.

To compare different conditions or events, one is often subtracted from the other.

# Psychophysiology

## Part 8.2: Electrocortical measures



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