Foundations of Psychophysiology

Part 8.2: Electrocortical measures

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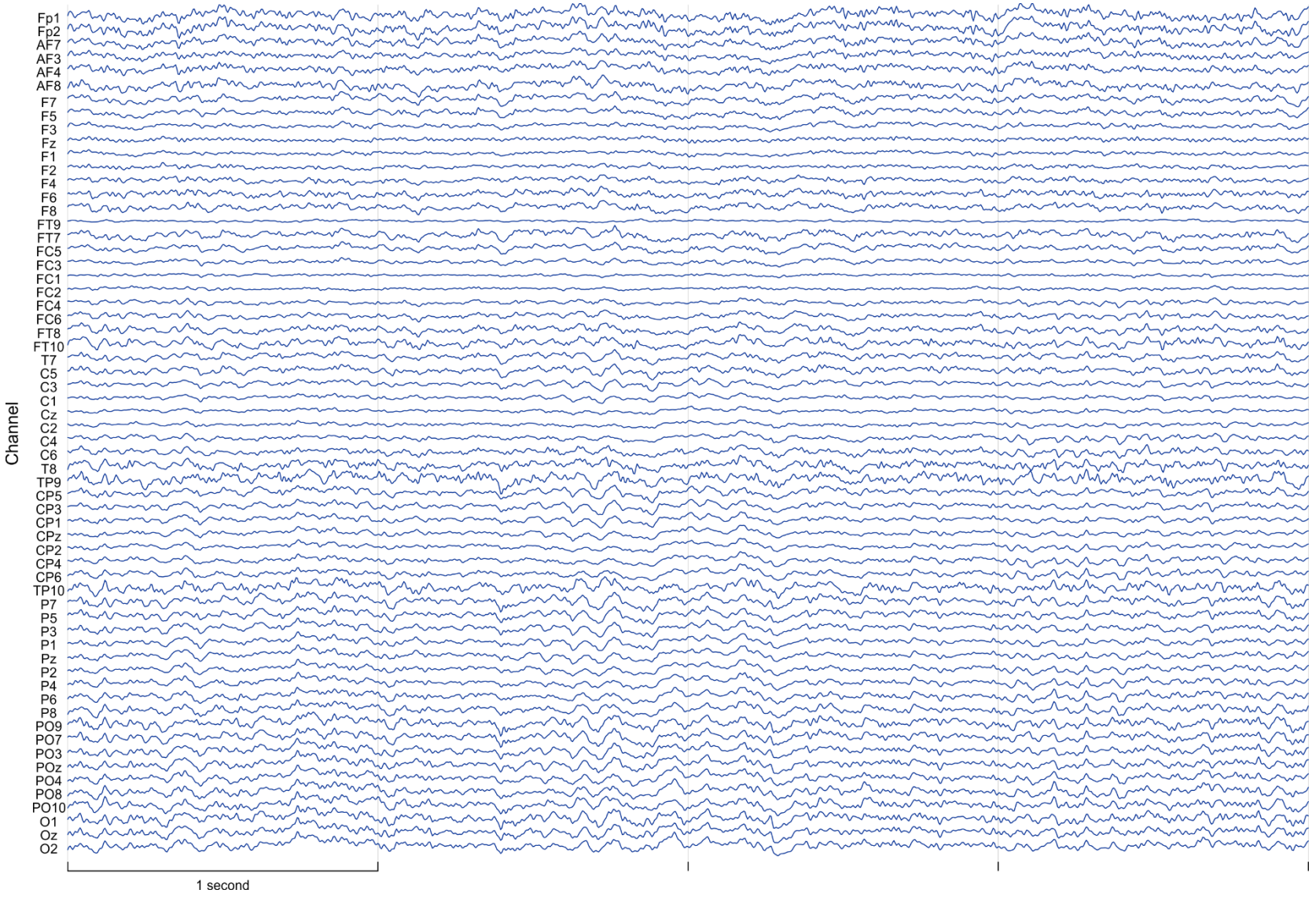
Psychophysiology: Electrocortical measures

The electroencephalogram



Electrocortical measures

Recording an EEG

Spontaneous EEG activity

Frequency domain analysis

Time domain analysis

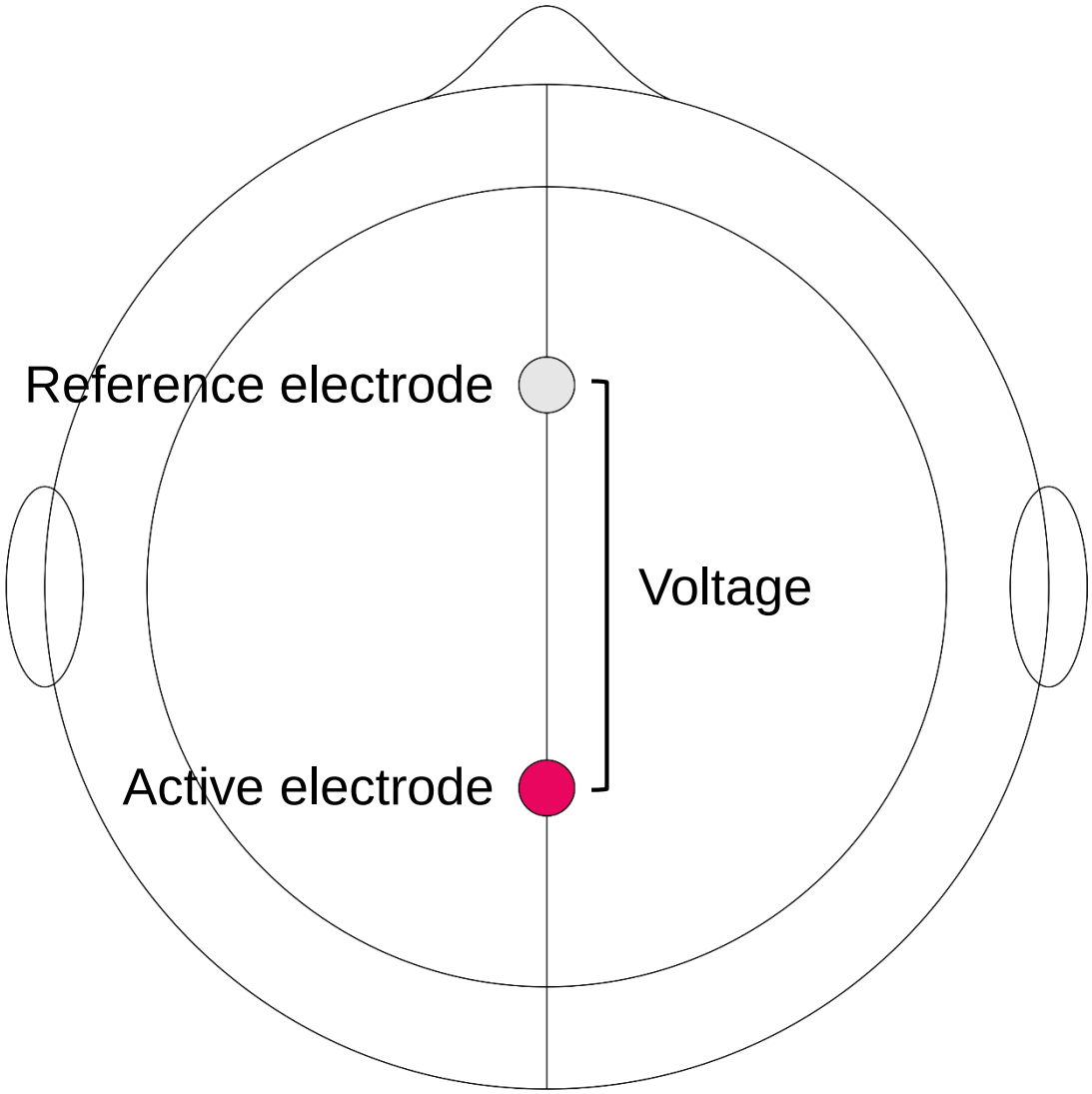
Time-frequency analysis

Time-time analysis

Recording an EEG

Psychophysiology: Electrocortical measures: Recording

Electrodes



The reference electrode

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

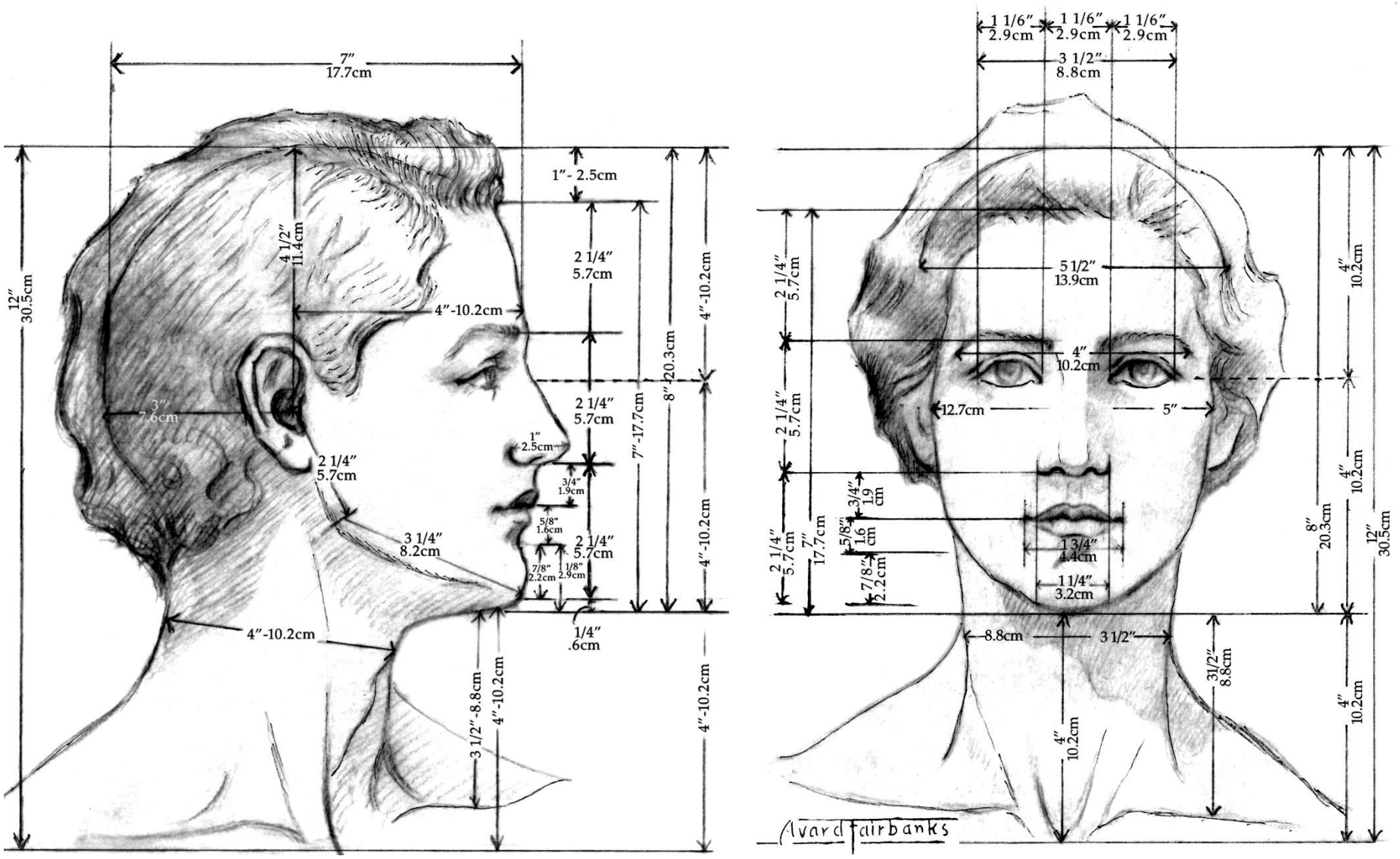
However, there is no "electrically neutral" reference location on the human body.

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.

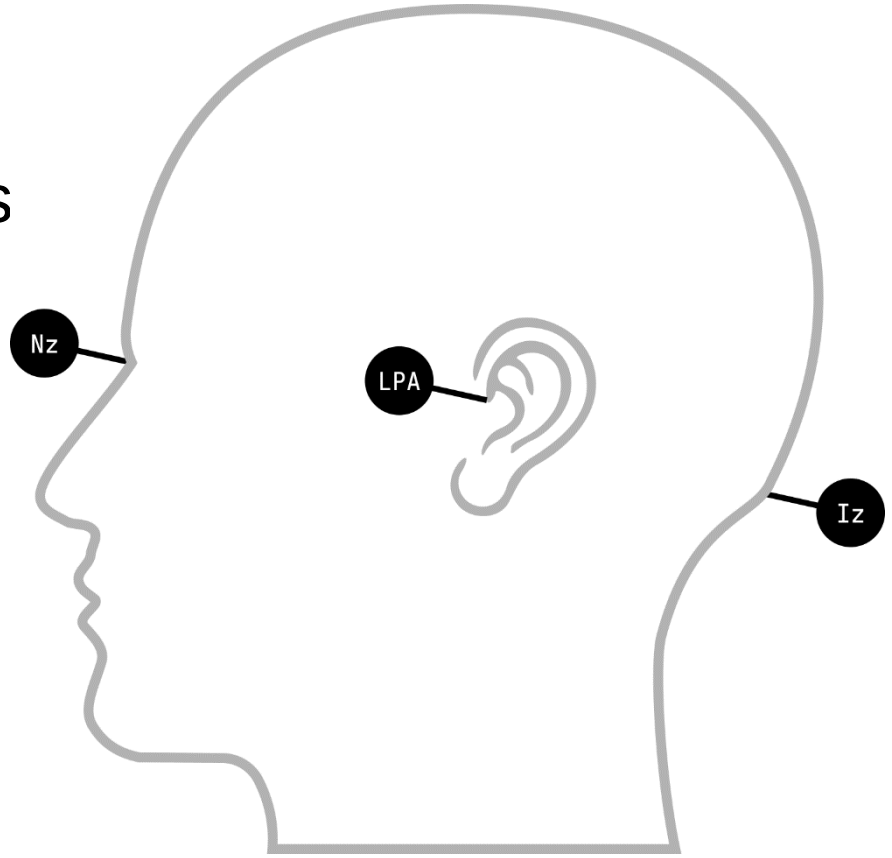
Reproducing electrode positions



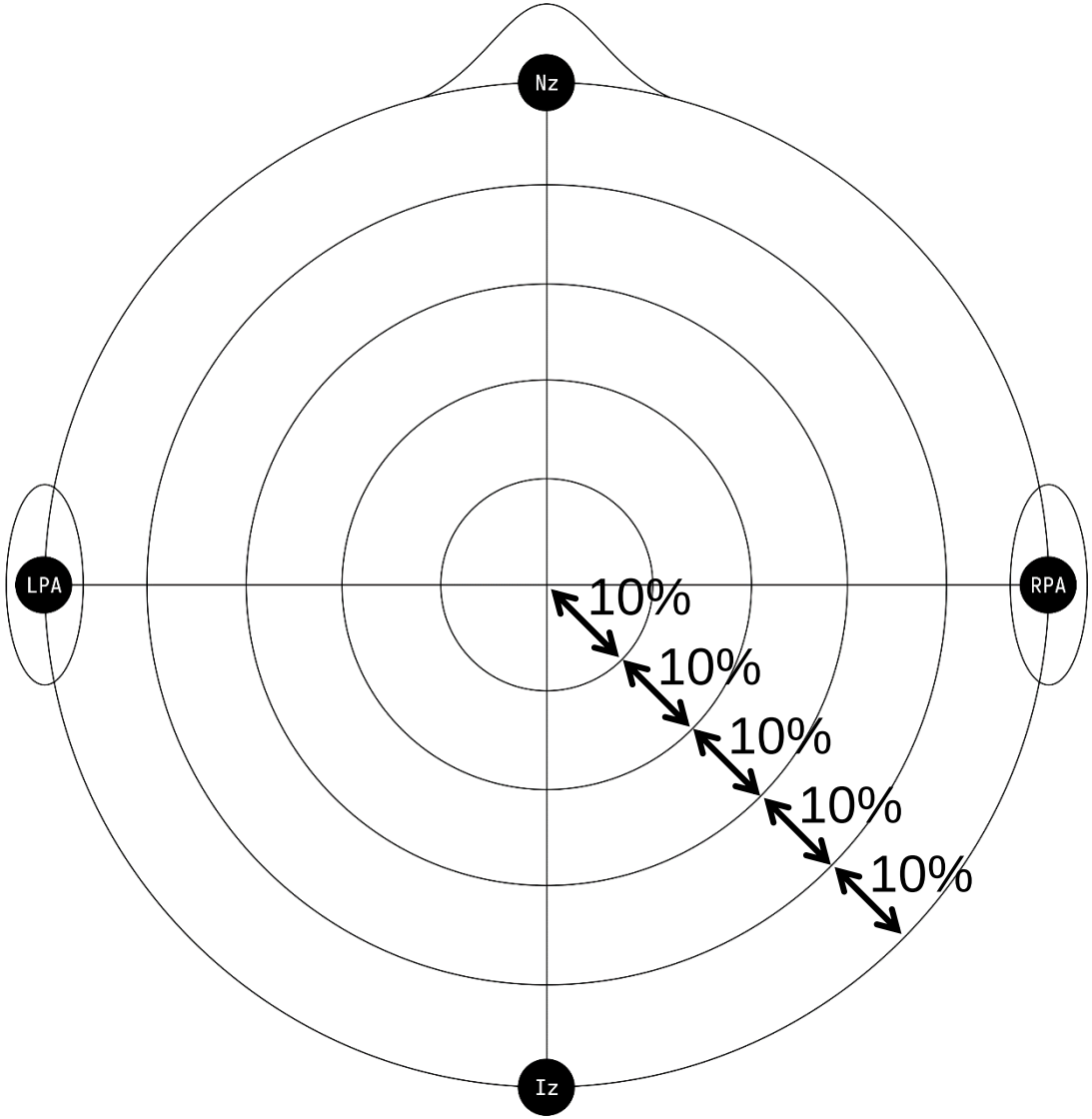
The international 10-20 system

Fiducials

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

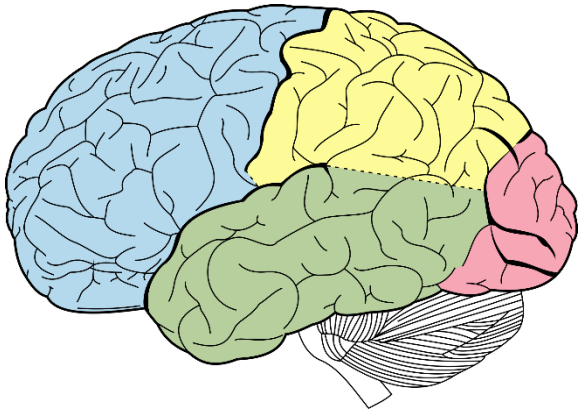


The international 10-20 system



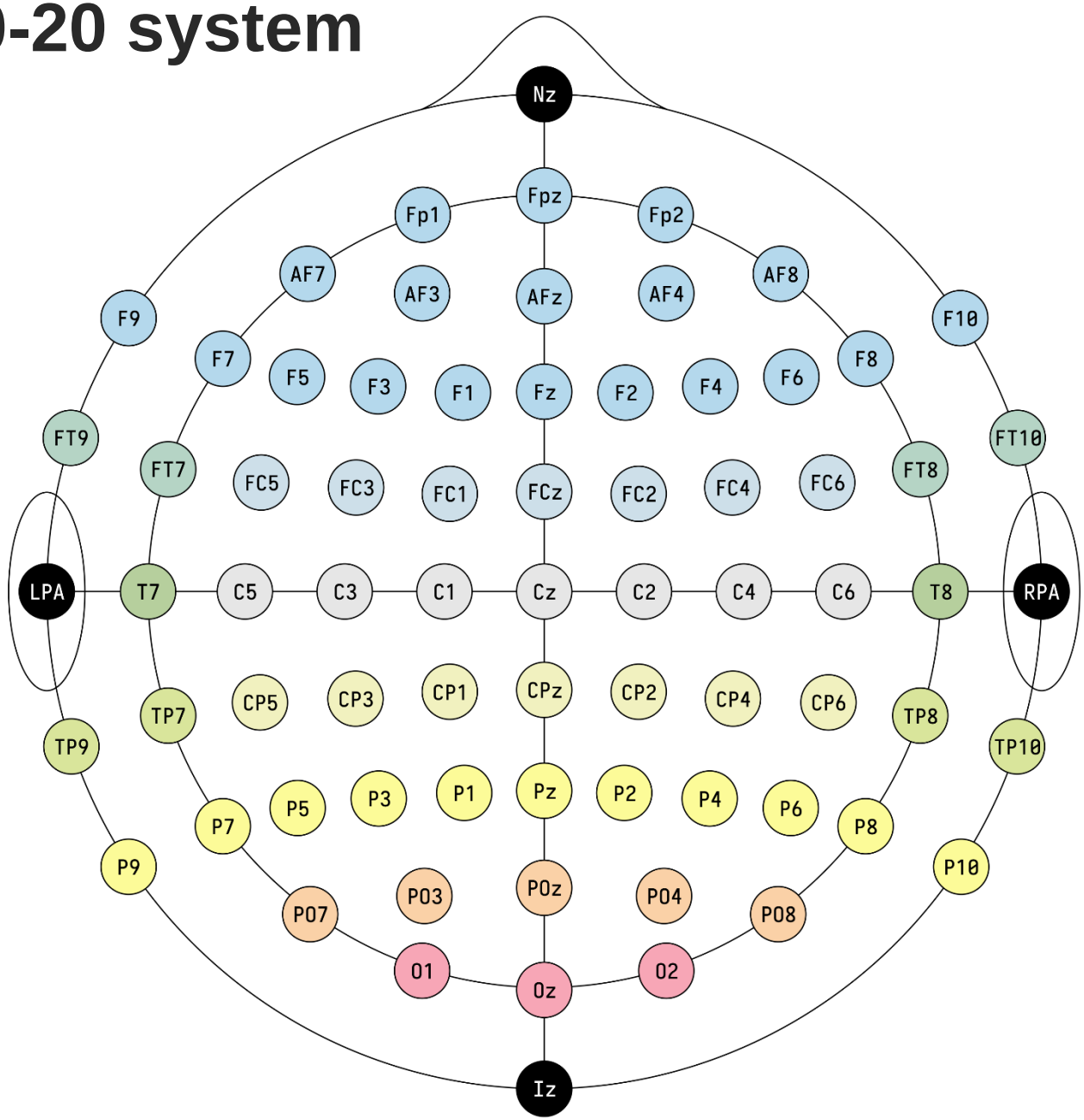
Psychophysiology: Electrocortical measures: Recording

The international 10-20 system



F – Frontal
C – Central
P – Parietal
O – Occipital
T - Temporal

Odd – Left
z – Midline
Even – Right



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.

Photo: © Brain Products GmbH

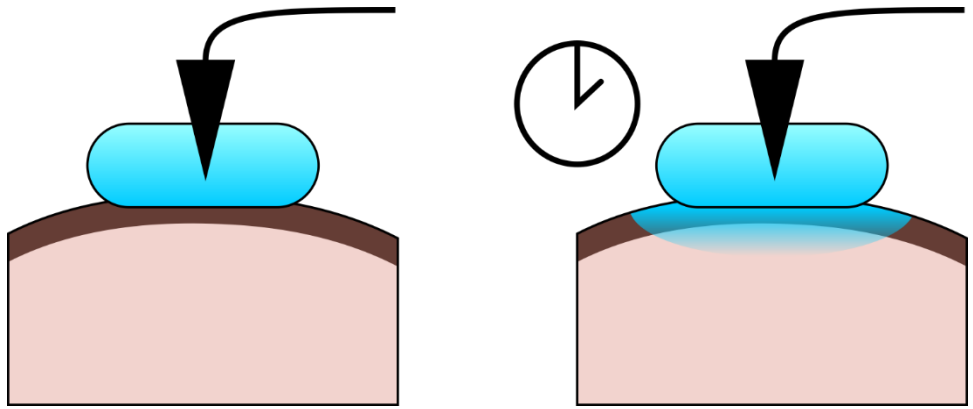
Applying electrodes

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 conducing electrolyte gel is used.

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

It also provides stability against mechanical movement.



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.

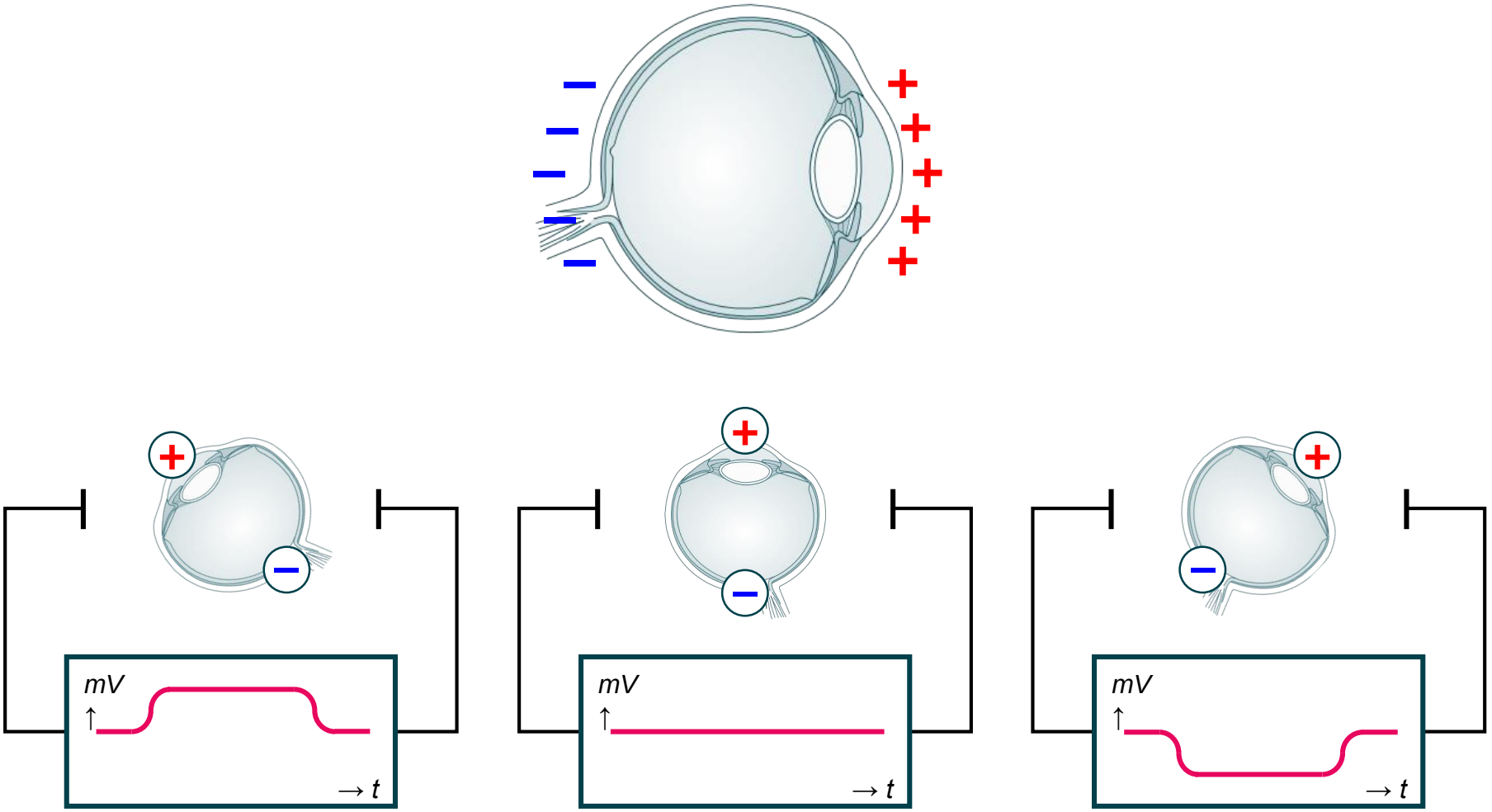
Artefacts

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

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

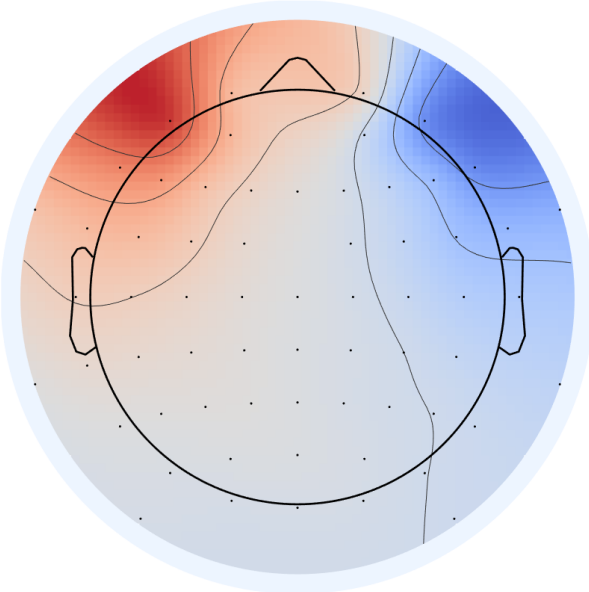
eye movements are a prominent source of artefacts in EEG recordings.

Eye movements



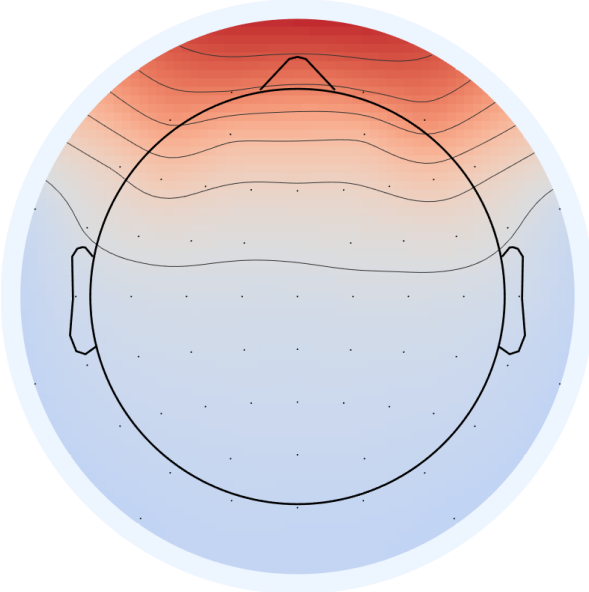
Eye movements

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



Horizontal movement

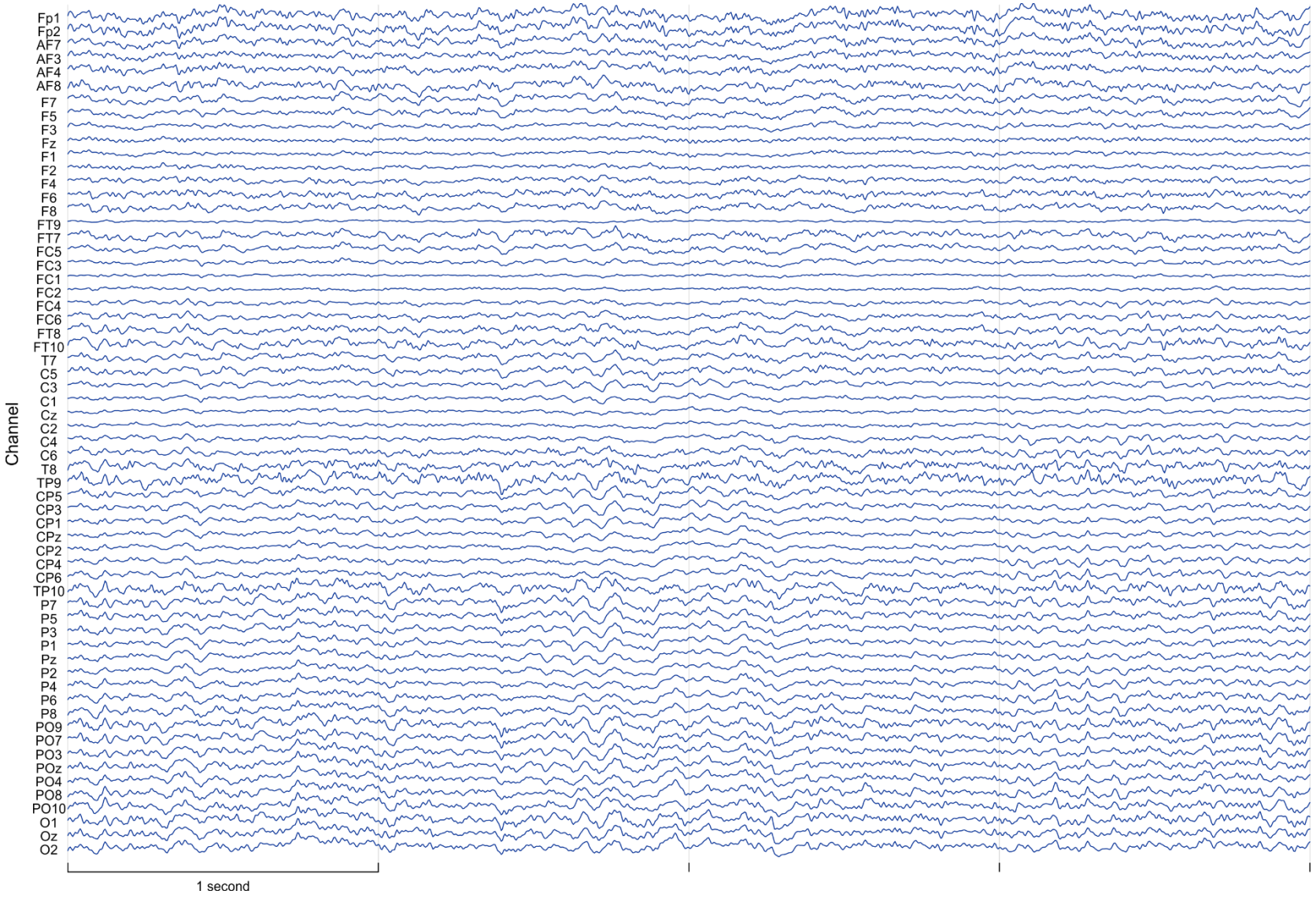
Eye blinks, due to the eyelid “closing” the cornea-scalp circuit, similarly affect EEG recordings.



Blinks

Spontaneous EEG activity

The electroencephalogram



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.

Spontaneous EEG activity

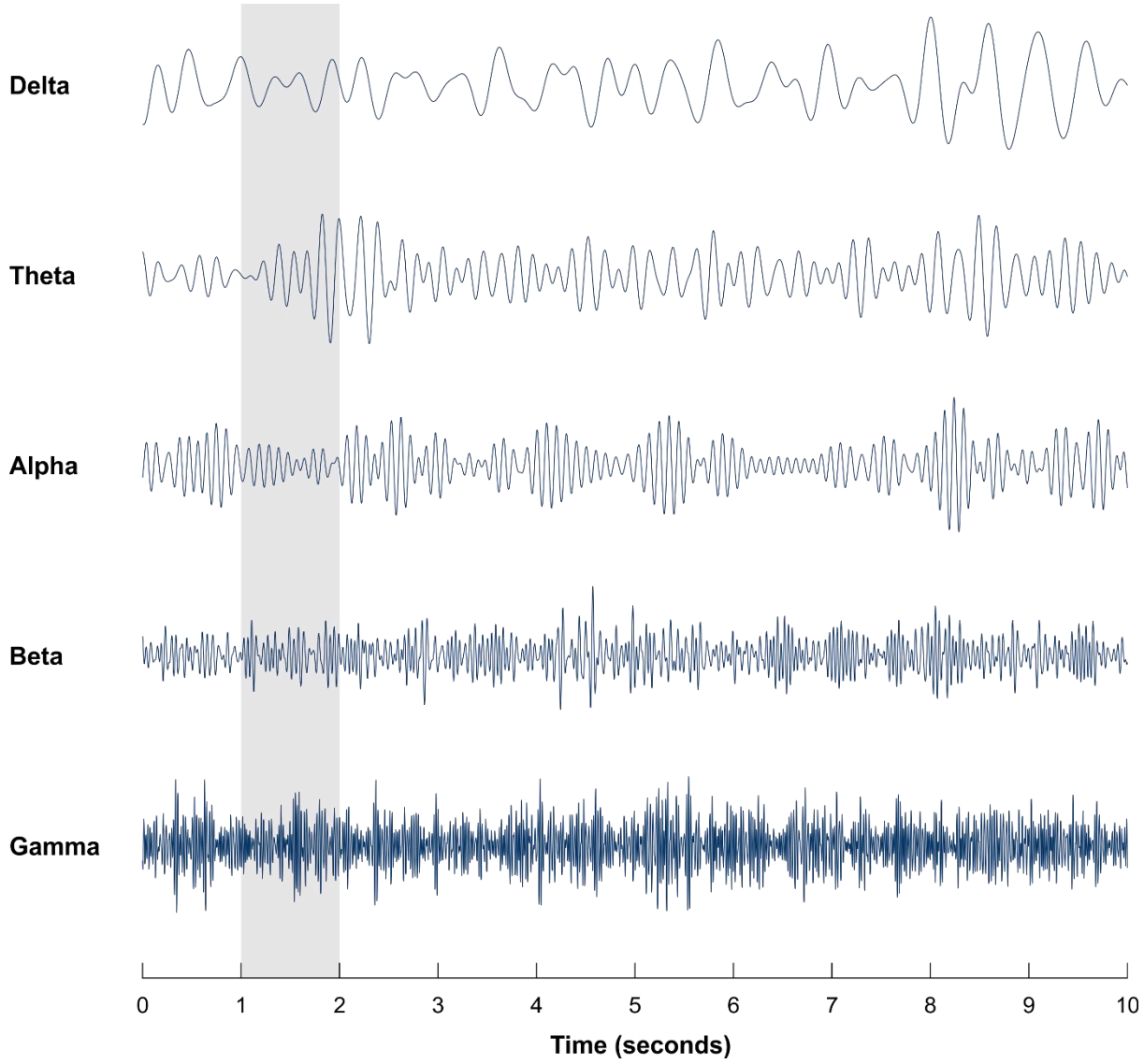
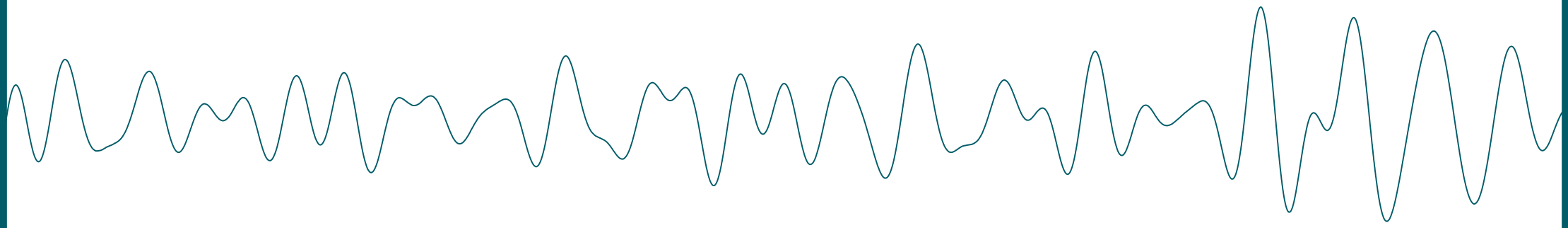


Figure by Irkrol is in the public domain

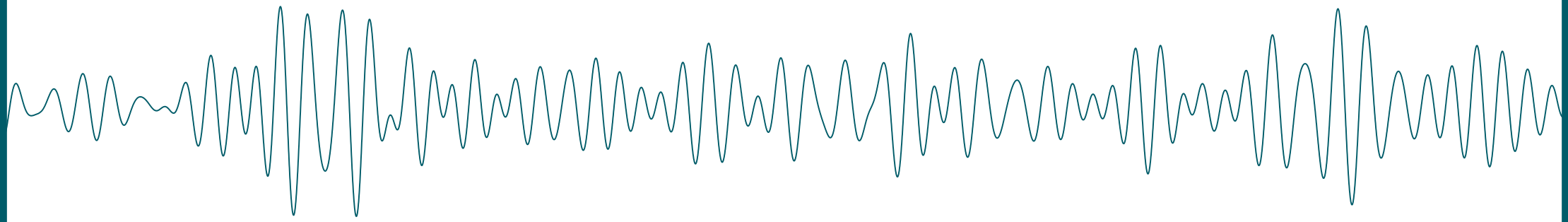
Delta rhythm (1-4 Hz)

- 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



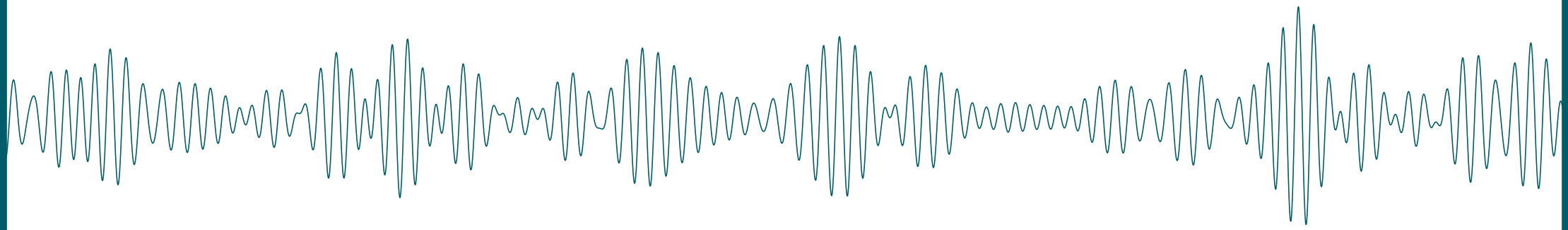
Theta rhythm (4-8 Hz)

- 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)



Alpha rhythm (8-12 Hz)

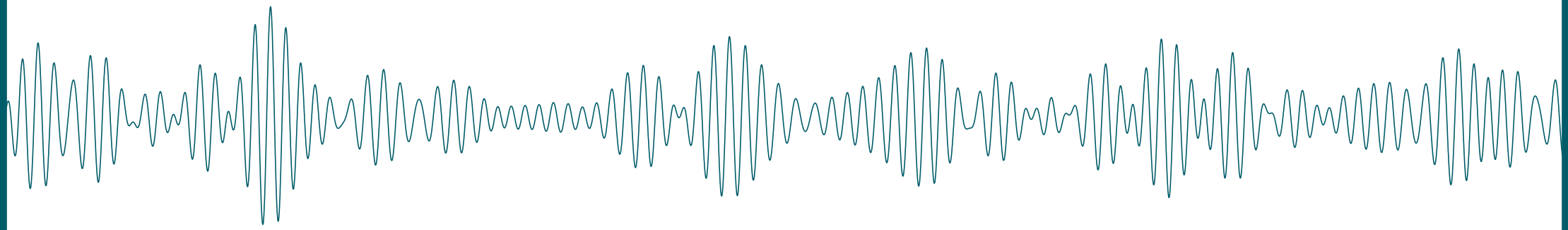
- Dominant regular frequency in human EEG (aside from bursts of delta activity)
- Most prominent during wakeful relaxation with closed eyes, primarily over occipital sites
- Alpha desynchronization (reduced alpha activity) is associated with attention and cognitive work, especially in combination with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



Mu (sensorimotor) rhythm (8-13 Hz)

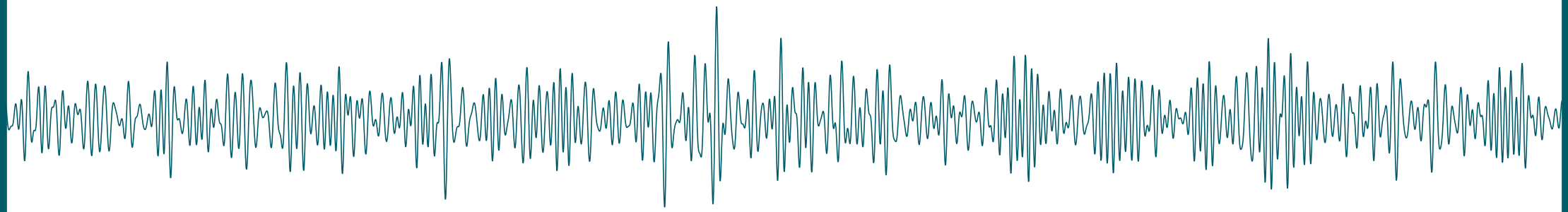
- Similar to alpha, but distinguished from the alpha rhythm by location: the mu rhythm is associated with the motor cortex

- Mostly observed when no motor actions are performed



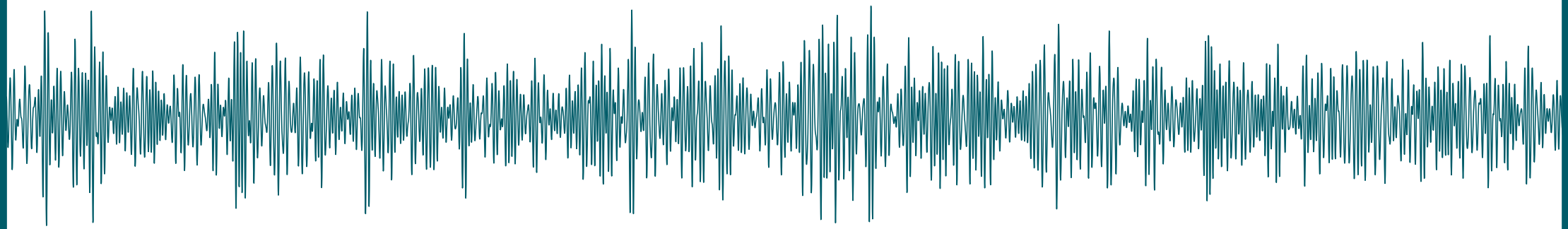
Beta rhythm (12-30 Hz)

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



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



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.

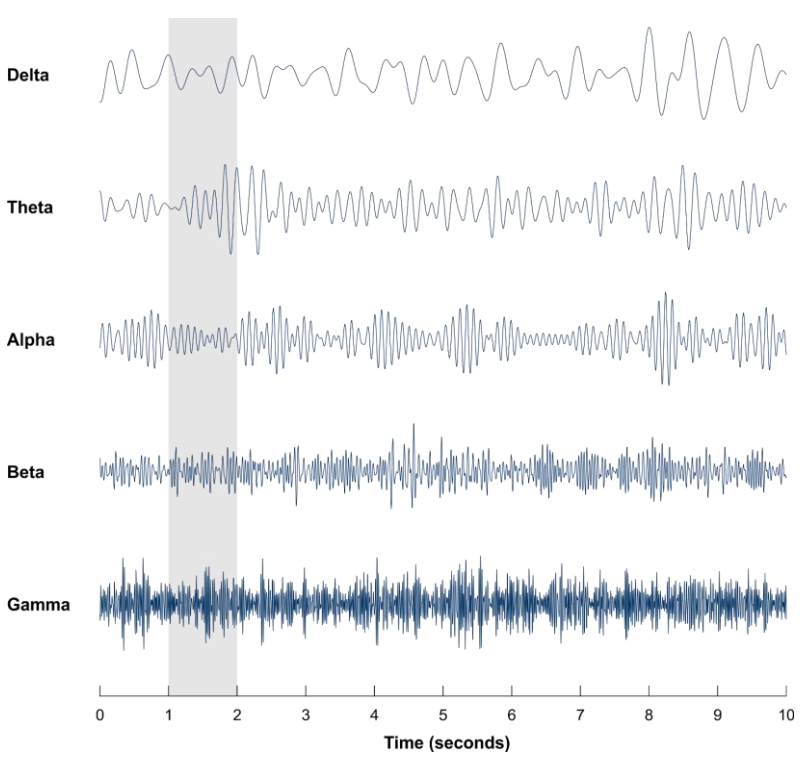
Peak frequencies vary across persons. Frequency band definitions are largely historical and vary from field to field, time to time, expert to expert.

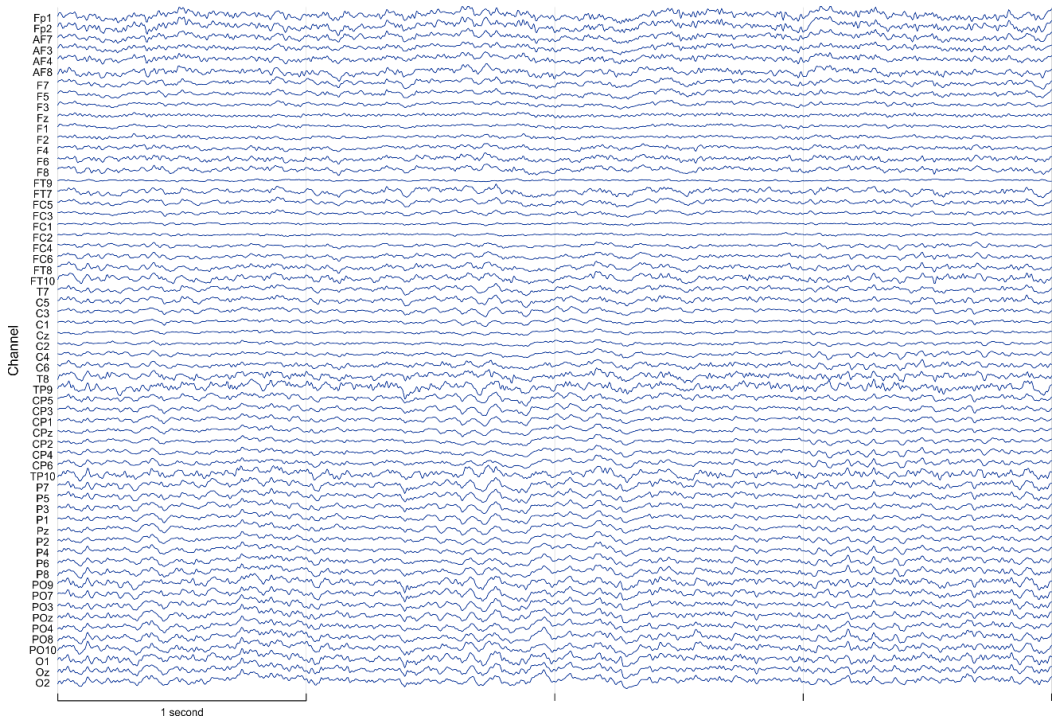
It is a gross simplification to simply equate activity of any frequency with any particular function.

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

EEG contains activity of all frequencies

All frequency bands are always represented in EEG.



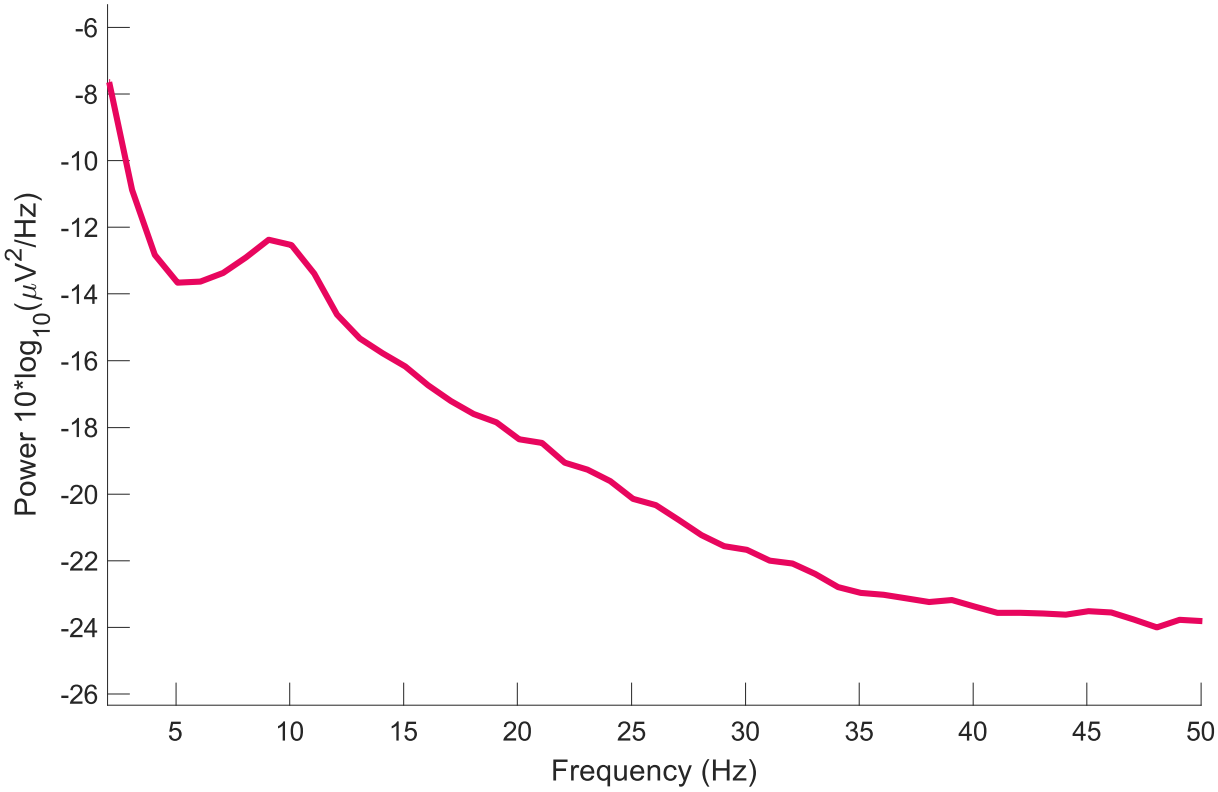


More generally, in fact, *any* signal can be decomposed into mixtures of different frequencies. (With EEG, some bands just have names.)

Frequency domain analysis

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.



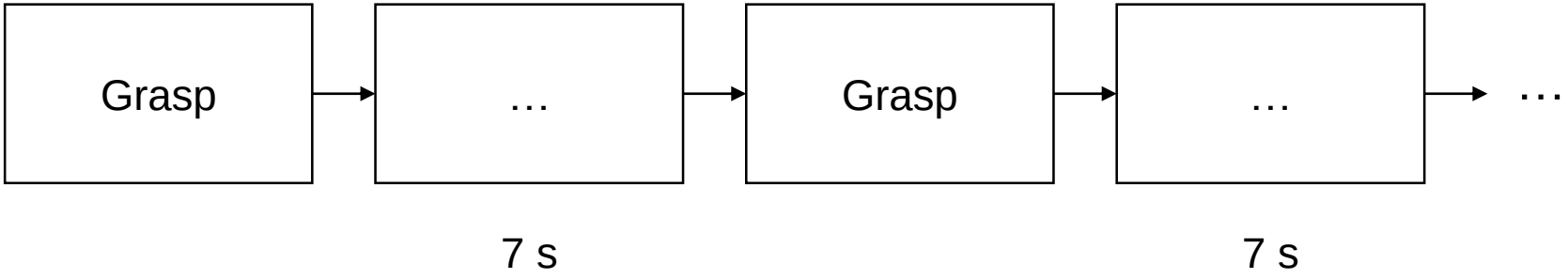
Example experiment: Mu-band desynchronisation

In different conditions, participants are asked to

a) rest, or

b) grasp an object

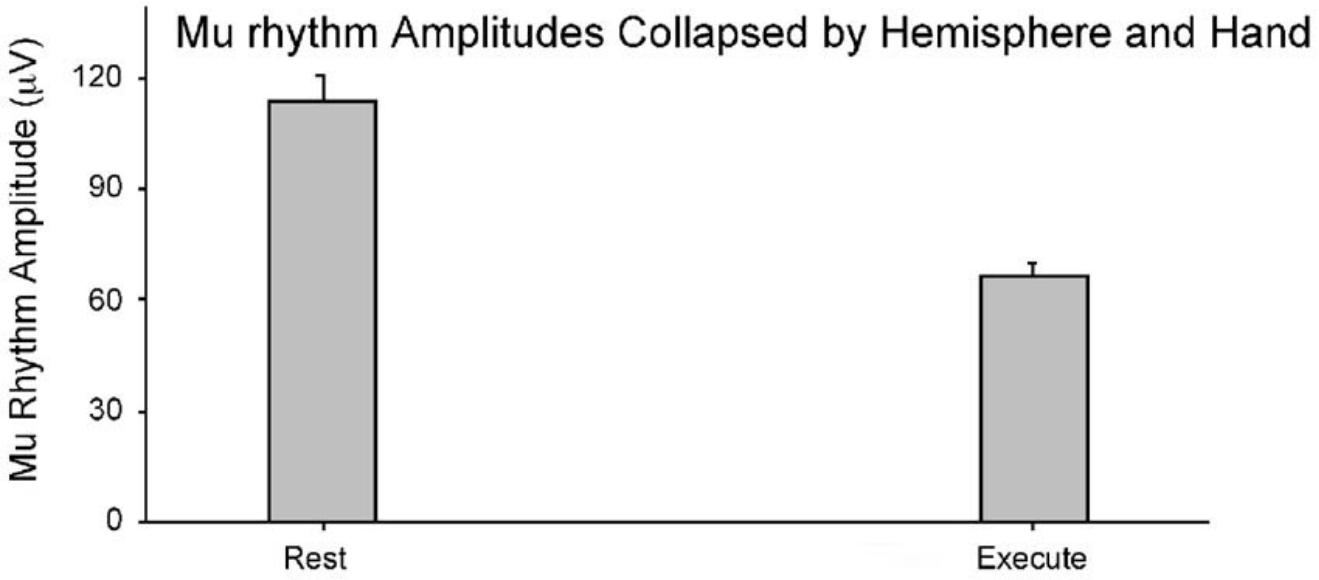
and repeat this multiple times with pauses in between.



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.

Example experiment: Mu-band desynchronisation

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



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.

Example experiment: Mu-band desynchronisation

The actual experiment had five conditions:

a) rest;

b) observe someone move their hand in a flat position;

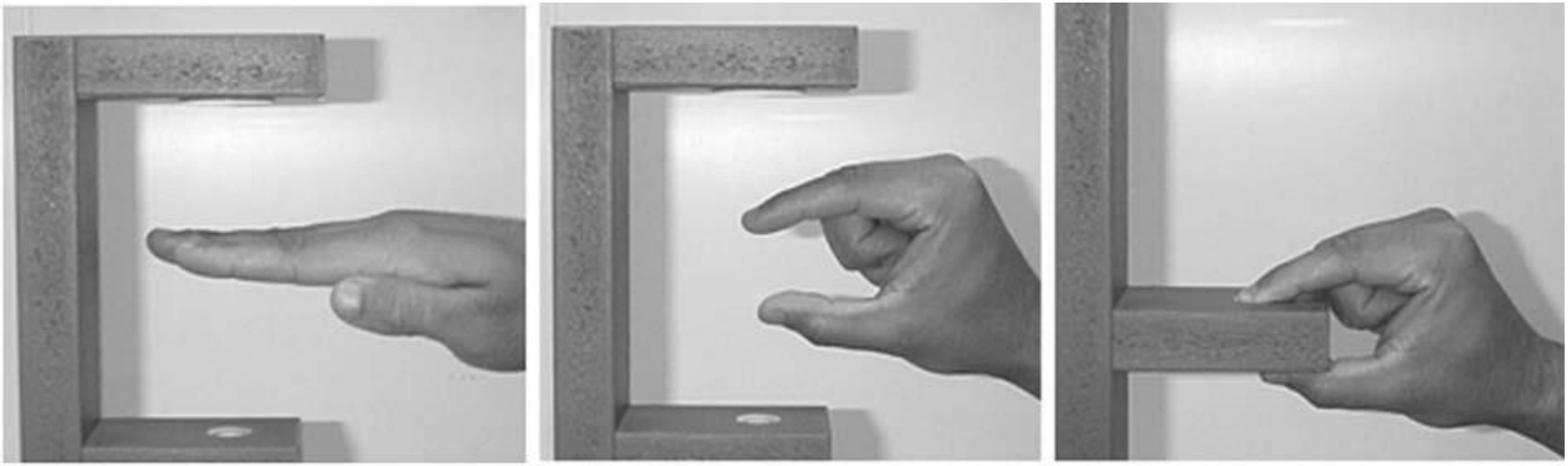
c) observe someone move their hand in a grasping motion;

d) observe someone move their hand to grasp an object;

e) grasp an object themselves.

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.

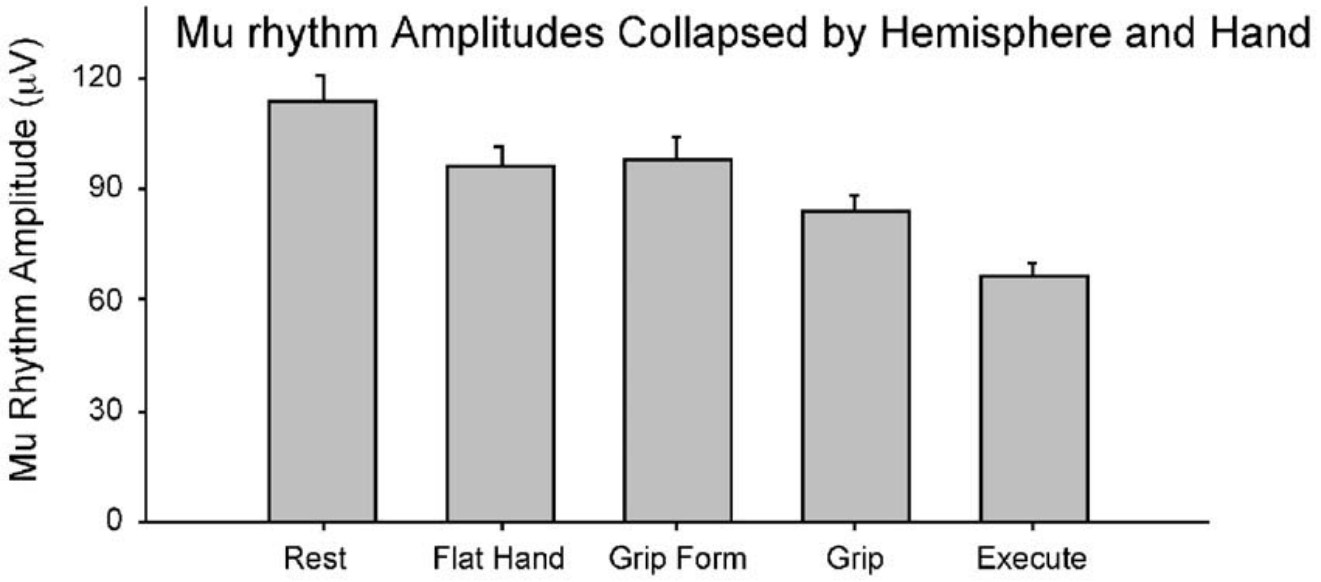
Example experiment: Mu-band desynchronisation



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.

Example experiment: Mu-band desynchronisation

The mu rhythm responded to both observed and executed movements.

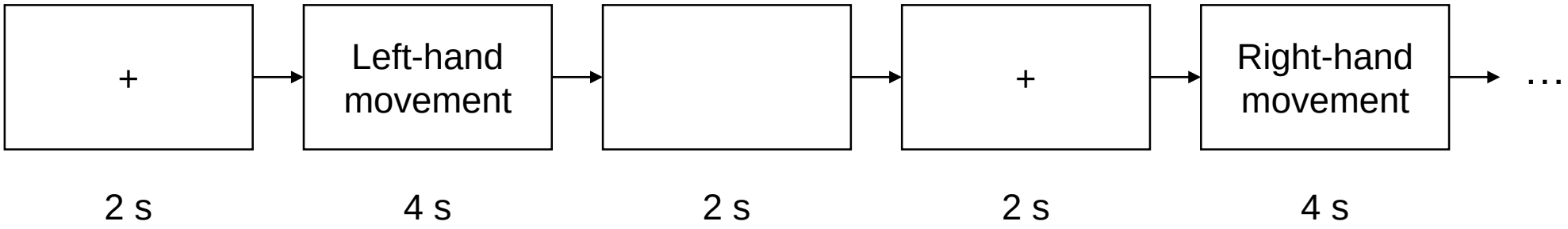


Muthukumaraswamy, S. D., Johnson, B. W., & McNair, N. A. (2004). Mu rhythm modulation during observation of an object-directed grasp. *Cognitive Brain Research, 19*(2), 195–201.

Example experiment: Motor imagery

The mu rhythm also responds to *imagined* movements.

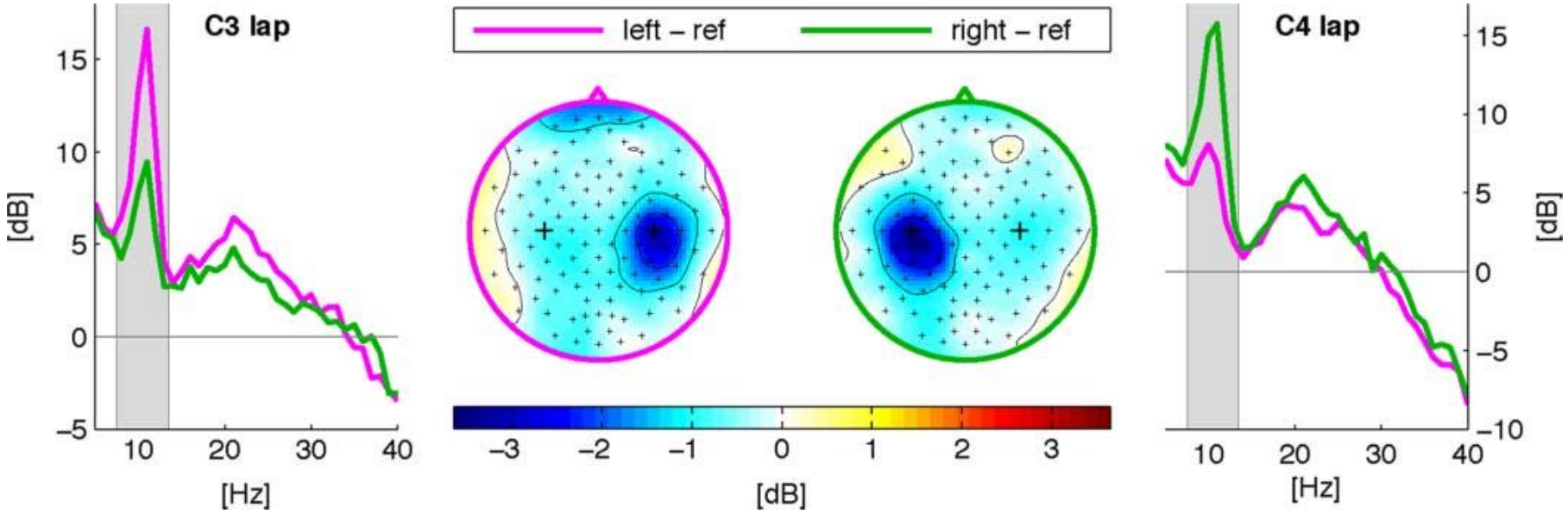
Motor imagery experiments generally ask participants to perform different kinds of imagined movement, e.g. different hands, feet, …



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.

Example experiment: Motor imagery

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

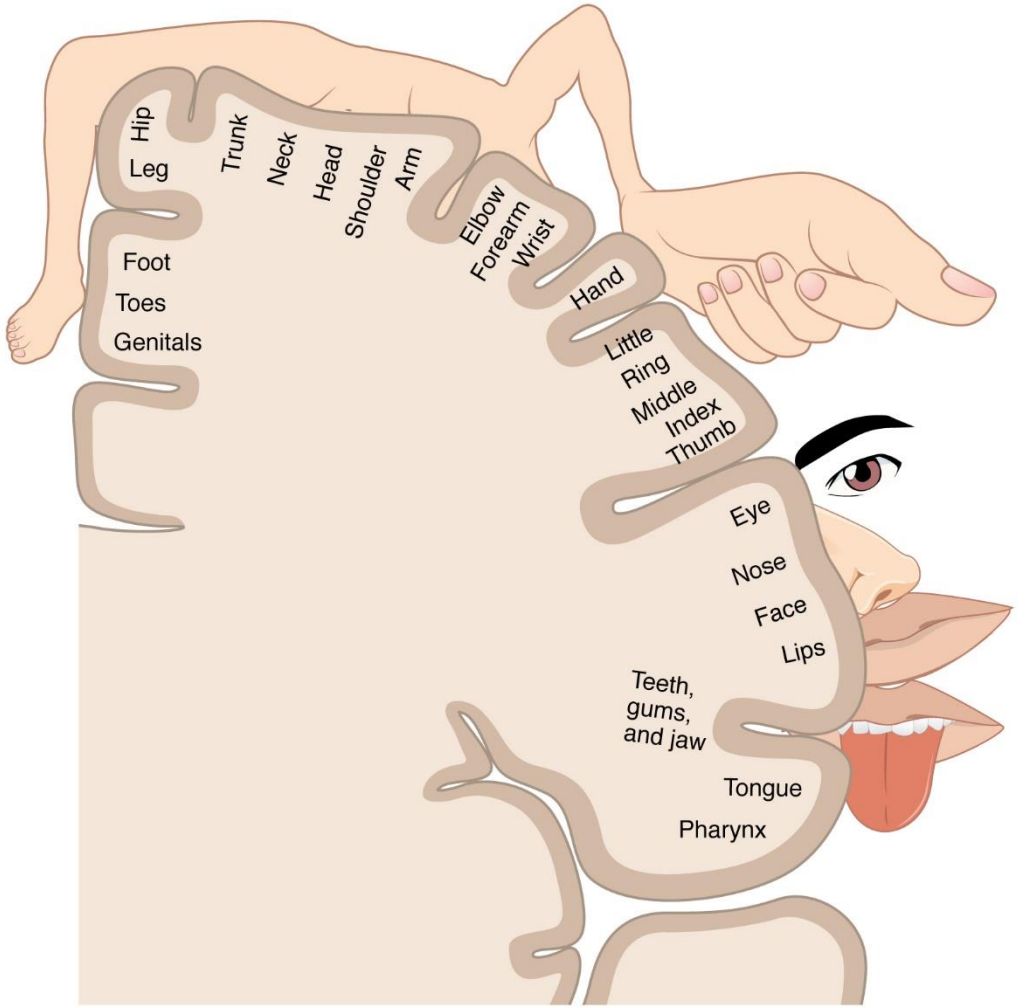


Maeder, C. L., Sannelli, C., Haufe, S., & Blankertz, B. (2012). Pre-stimulus sensorimotor rhythms influence brain–computer interface classification performance. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 20*(5), 653–662.

Example experiment: Motor imagery

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

This organisation is *contralateral*.



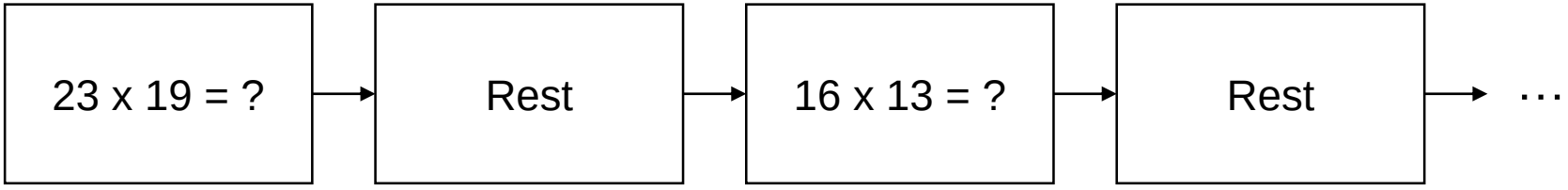
Example experiment: Workload

Participants are asked to

a) rest

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

for a few seconds each, and then repeat.



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.

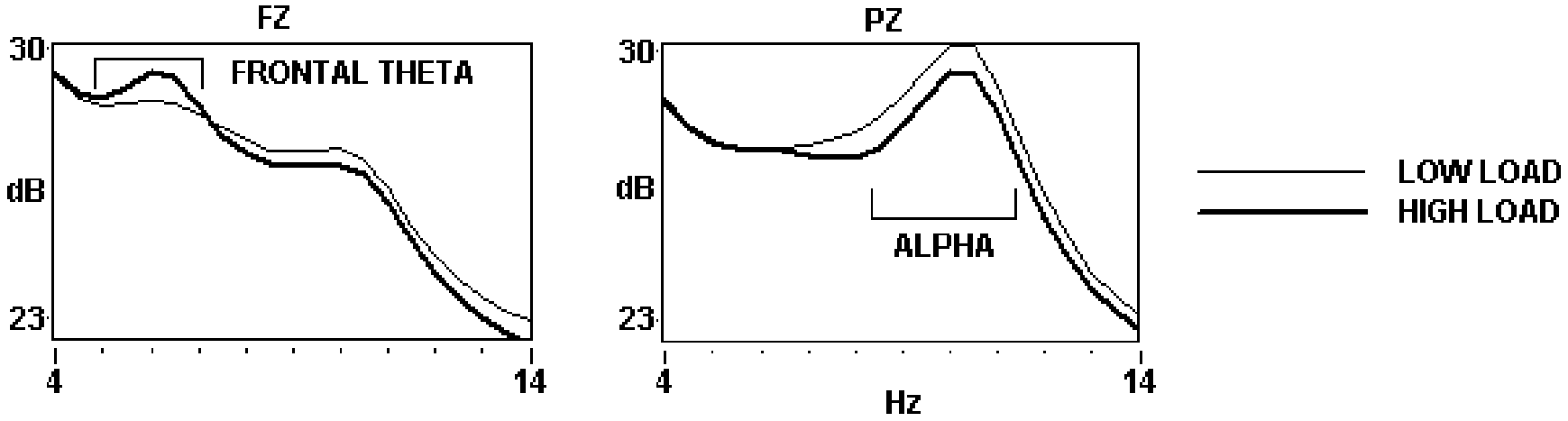


Figure: Gevins, A., & Smith, M. E. (2003). Neurophysiological measures of cognitive workload during human-computer interaction. *Theoretical Issues in Ergonomics Science, 4*(1–2), 113–131.

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.

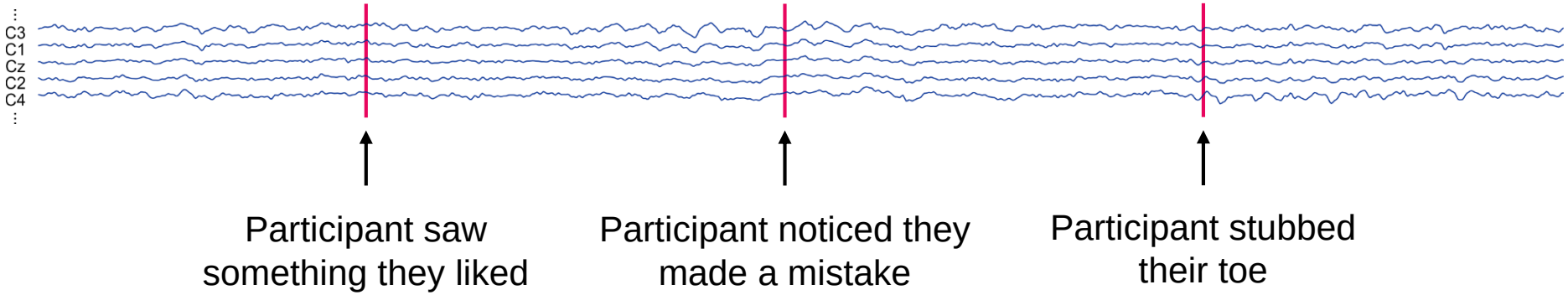
As such, we can for example differentiate between different types of imagined movement, and phases of high and low mental load.

Psychophysiology: Electrocortical measures

Time domain analysis

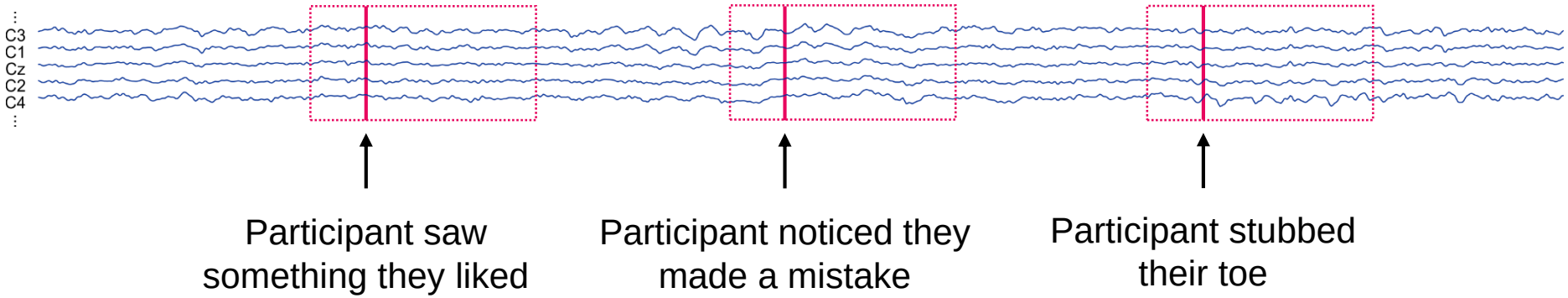
Event-related analysis

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



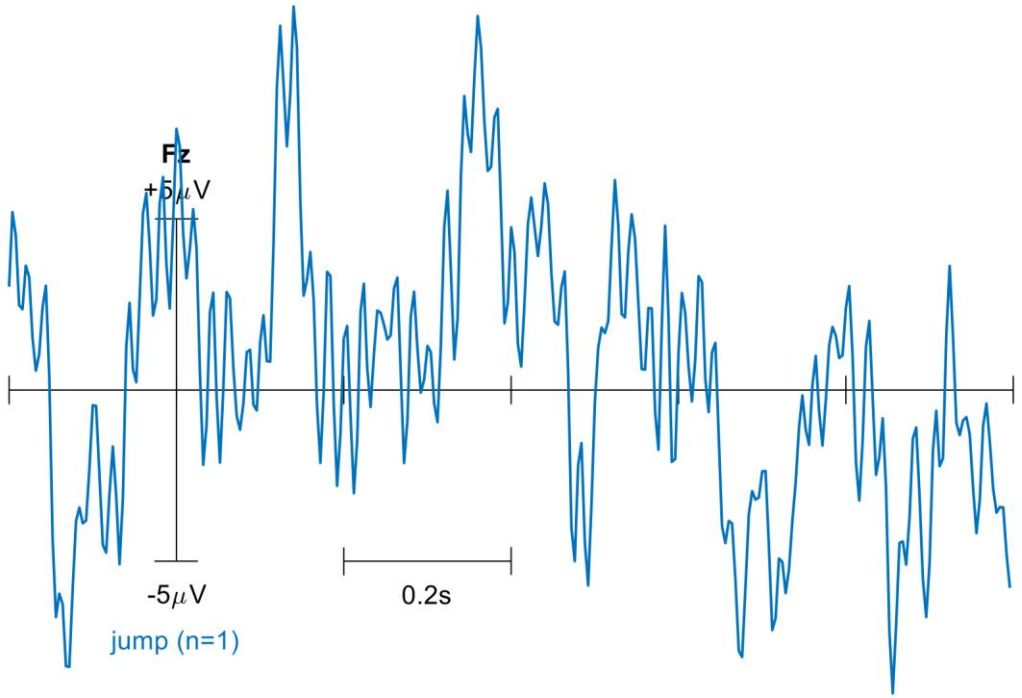
The event-related potential (ERP)

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



Epoching and ERP averaging

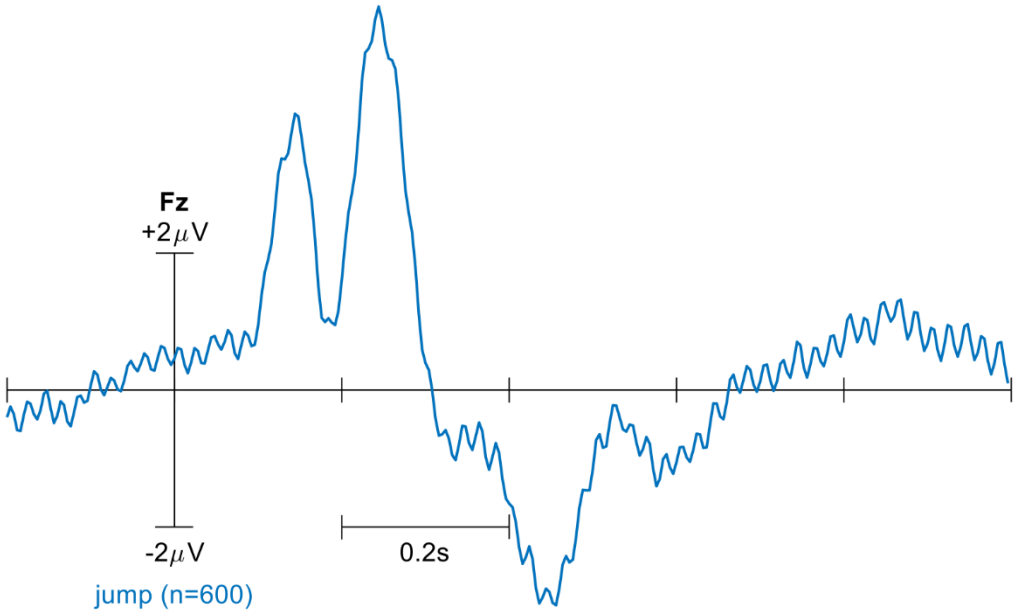
Looking at one such ERP, you will probably find nothing.



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

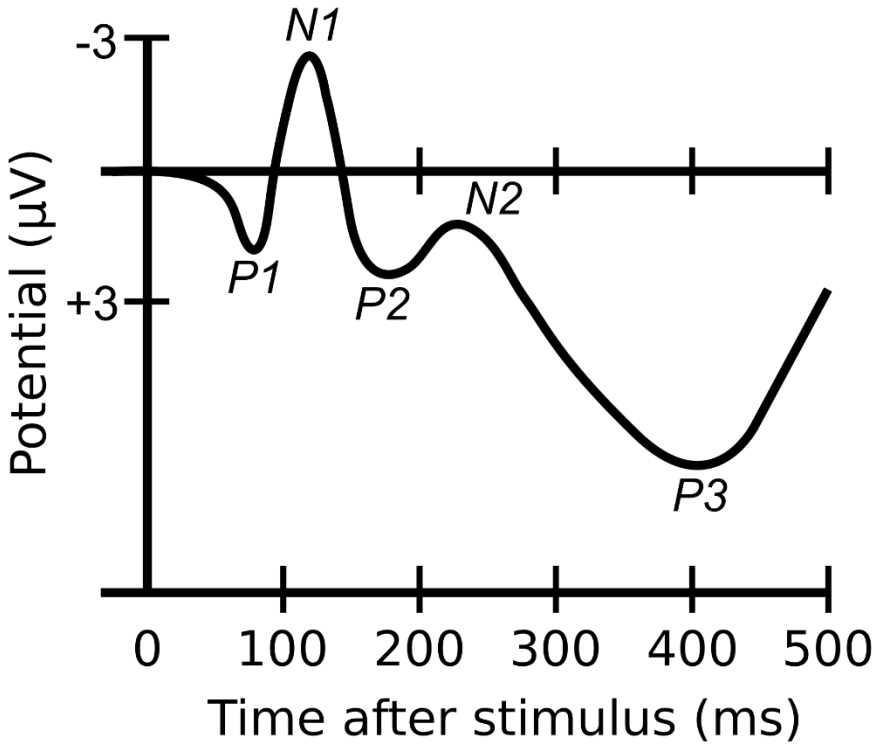
Epoching and ERP averaging

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.

ERP components



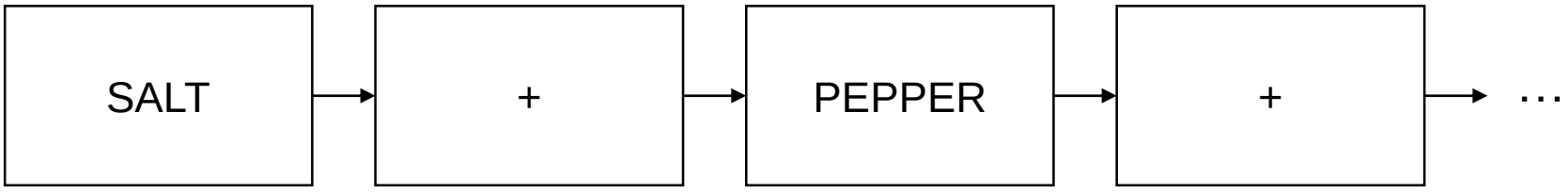
Example experiment: Word semantics

Participants are shown one word. The next word is either

a) related to the first word, or

b) unrelated to the first word.

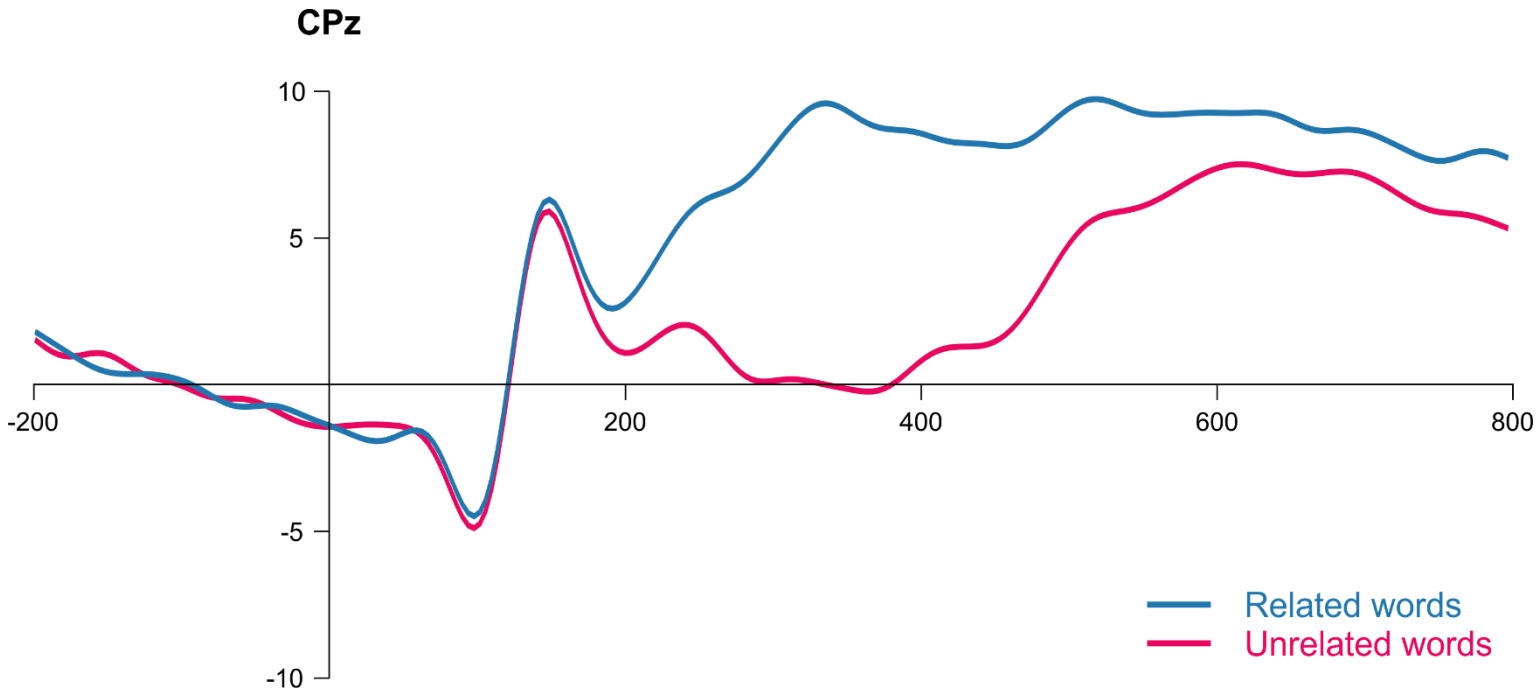
This is repeated for many word pairs.



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.

Example experiment: Word semantics

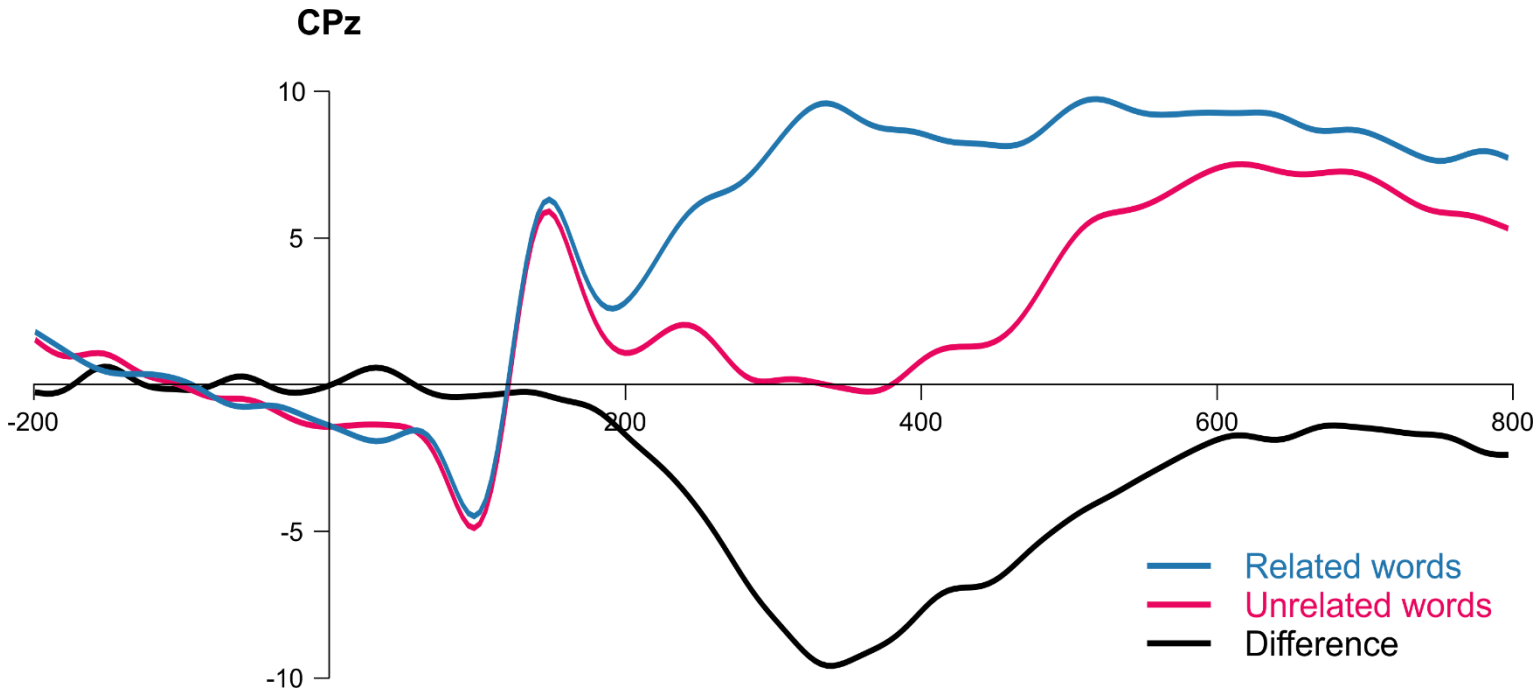
Comparing the event-related potential for relevant and non-relevant words, we see:



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.

Difference wave

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



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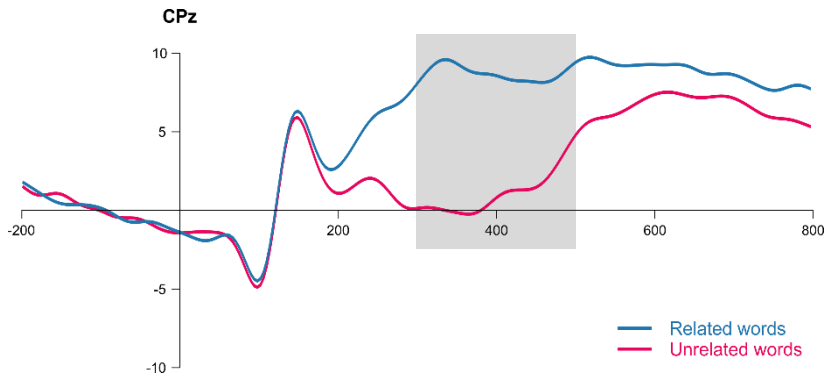
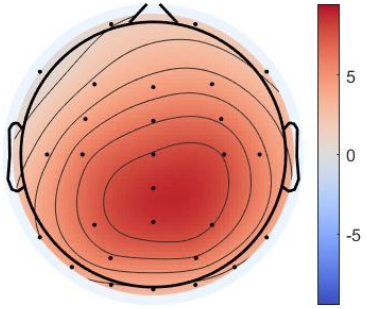
Spatial analysis of ERPs

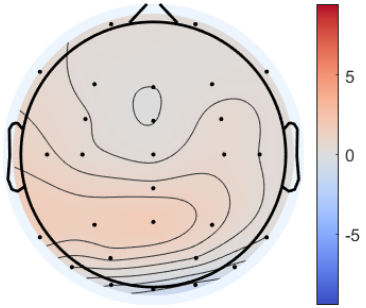
By topographically mapping each channel's ERP amplitude, it can also be analysed spatially.



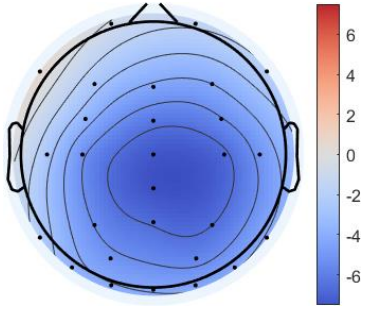


Mean amplitude between 300 and 500 ms for:

Related words



Unrelated words



Difference

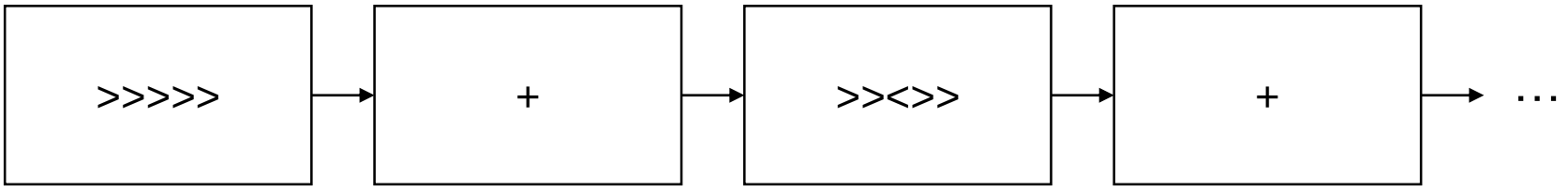
Data from: Kappenman, E. S., Farrens, J. L., Zhang, W., Stewart, A. X., & Luck, S. J. (2021). ERP CORE: An open resource for human event-related potential research. *NeuroImage, 225*, 117465.

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

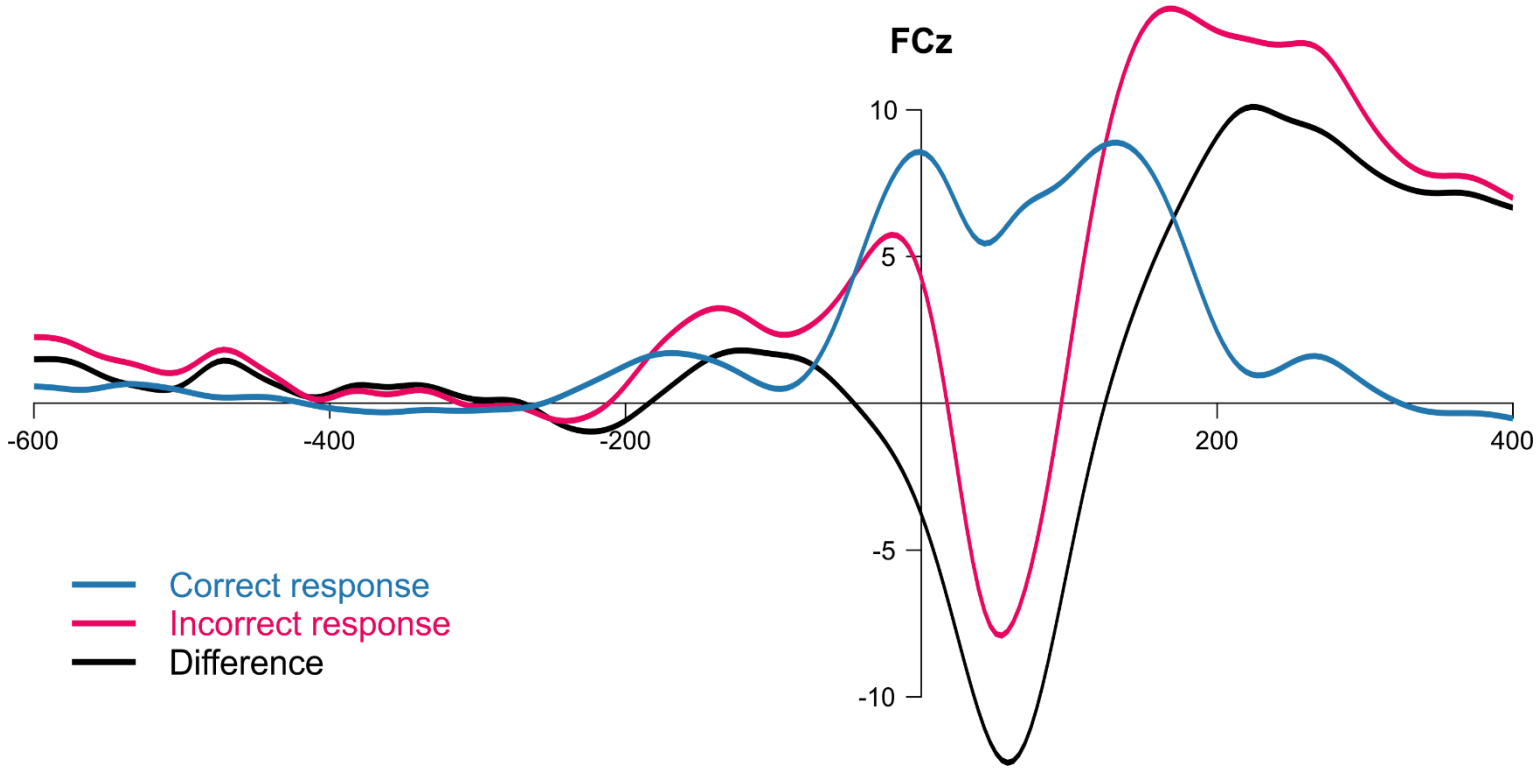
b) point in the other direction (incongruent: confusing).



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.

Example experiment: Flanker test

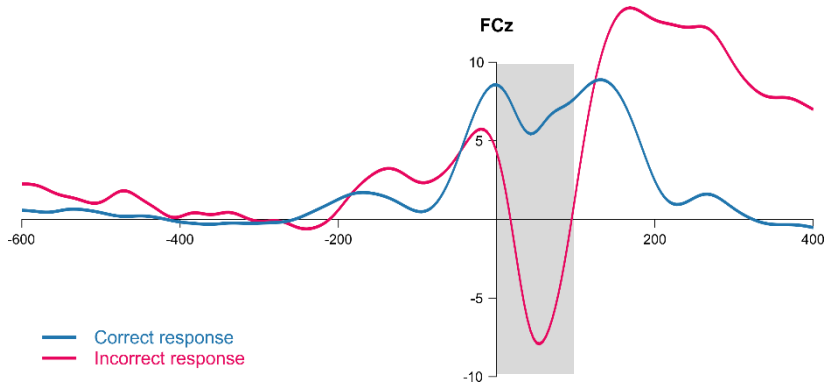
Comparing the event-related potential following correct versus incorrect responses, we see:

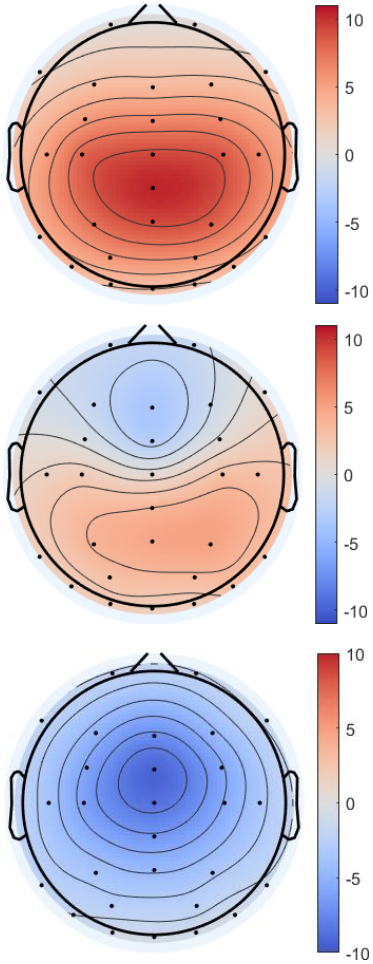


Data from: Kappenman, E. S., Farrens, J. L., Zhang, W., Stewart, A. X., & Luck, S. J. (2021). ERP CORE: An open resource for human event-related potential research. *NeuroImage, 225*, 117465.

Example experiment: Flanker test

The differential activity projects primarily onto frontal sites.





Mean amplitude between 0 and 100 ms for:

Correct responses

Incorrect responses

Difference

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.

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.

Time-frequency analysis

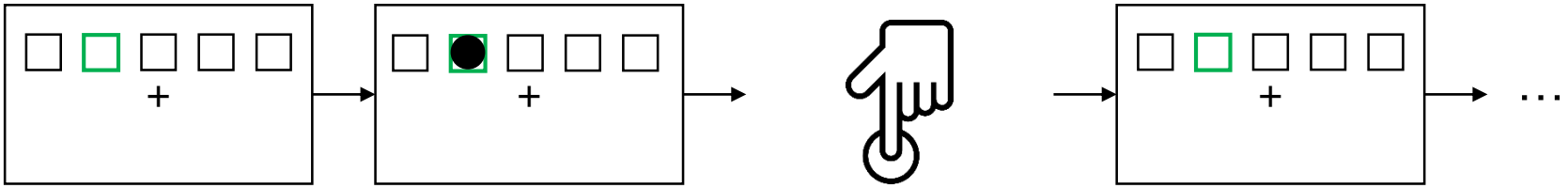
Time-frequency analysis

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.

Example experiment: Go/NoGo button press

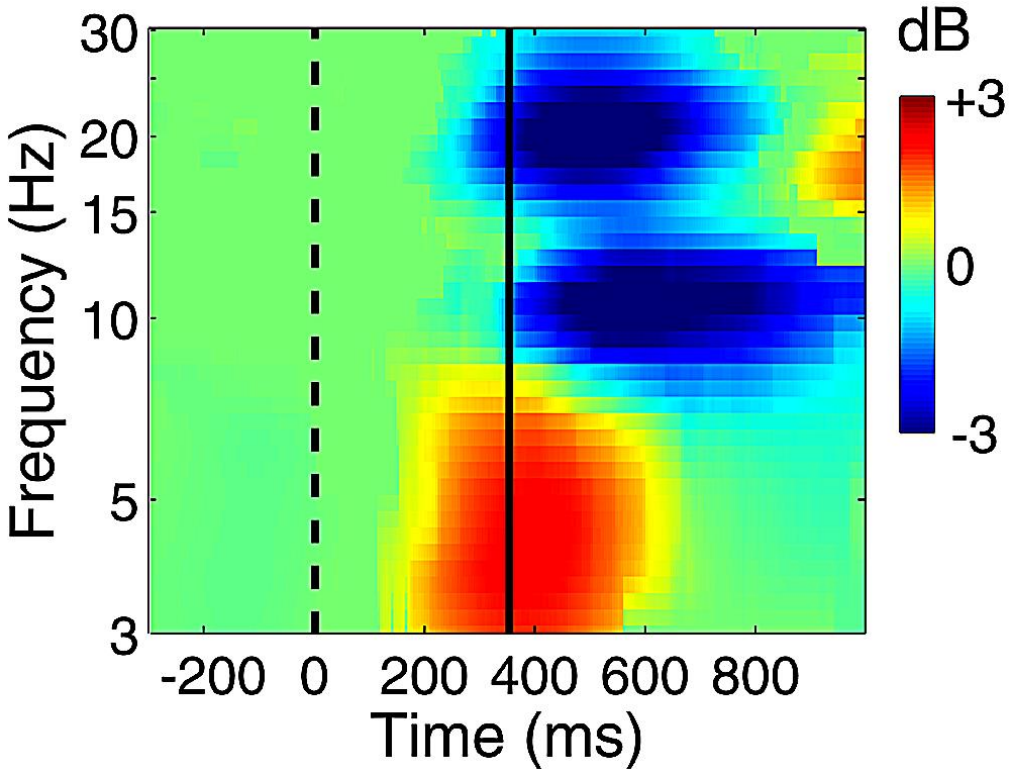
Participants attended to one coloured square out of five. They pressed a button when a stimulus appeared in the attended square.



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.

Event-related spectral perturbation (ERSP)

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



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. Note: IC-level result, not channel-level.

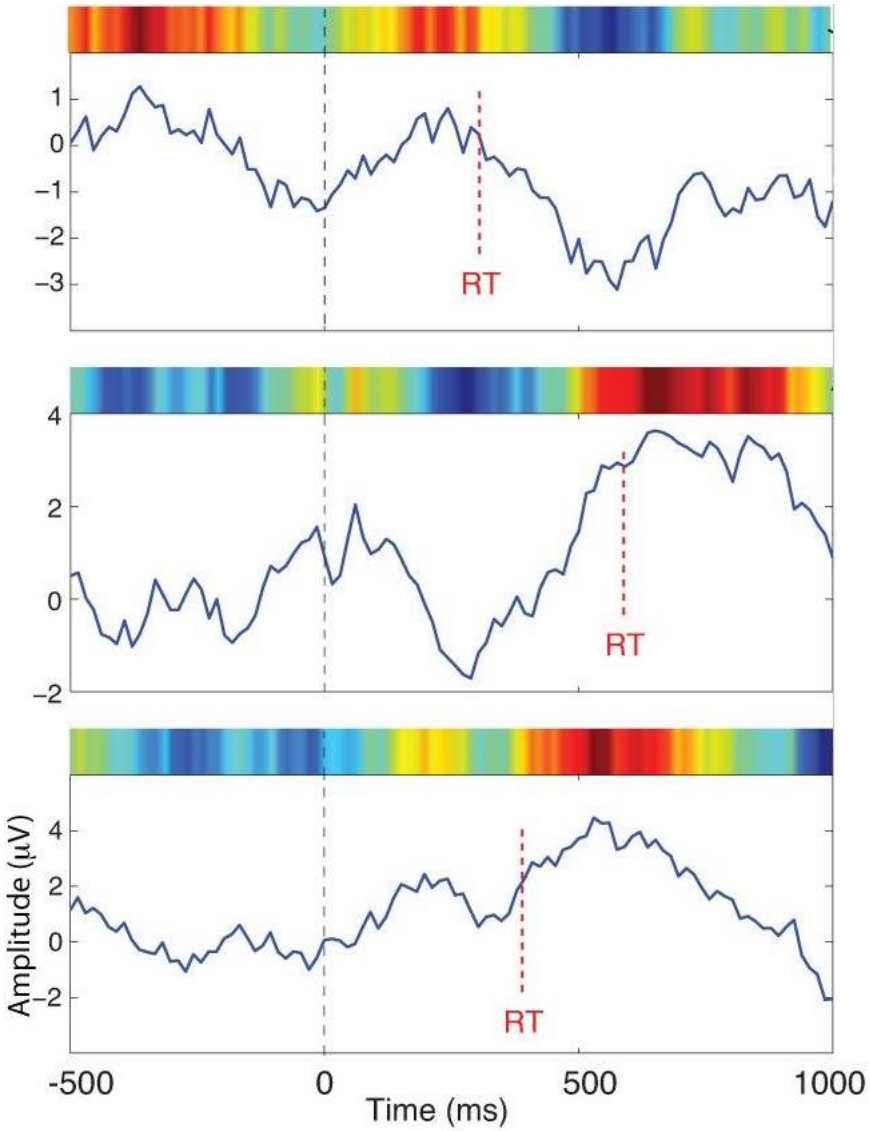
Time-time analysis

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.

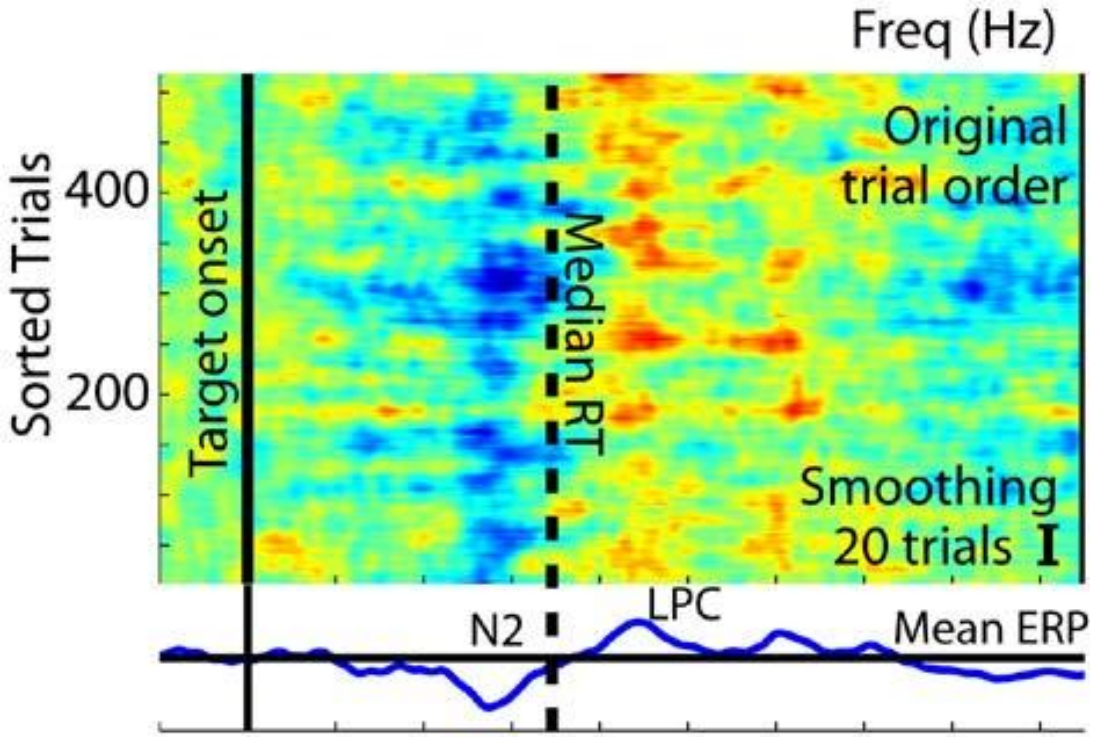
First, the single-trial ERP amplitudes are colour-coded.



Makeig, S., & Onton, J. A. (2011). ERP features and EEG dynamics: An ICA perspective. In S. J. Luck & E. S. Kappenman (Eds.), The Oxford handbook of event-related potential components (pp. 51–107). New York, NY: Oxford University Press.

Time-time analysis

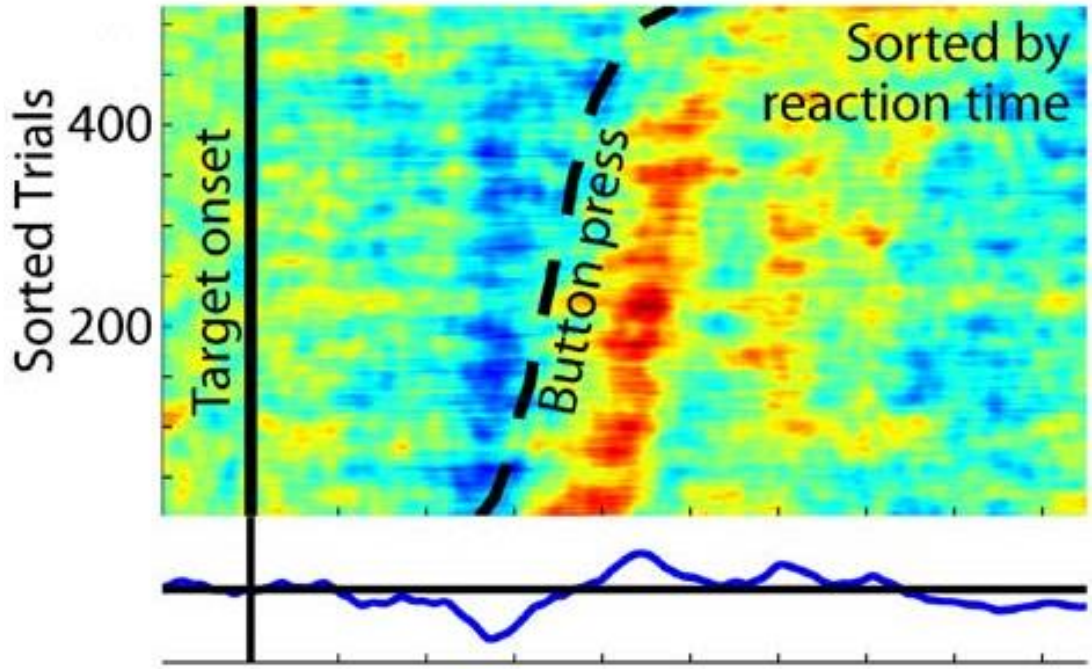
Stacking multiple colour-coded single-trial ERPs creates an ERP image.



Makeig, S., & Onton, J. A. (2011). ERP features and EEG dynamics: An ICA perspective. In S. J. Luck & E. S. Kappenman (Eds.), The Oxford handbook of event-related potential components (pp. 51–107). New York, NY: Oxford University Press.

Time-time analysis

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



Makeig, S., & Onton, J. A. (2011). ERP features and EEG dynamics: An ICA perspective. In S. J. Luck & E. S. Kappenman (Eds.), The Oxford handbook of event-related potential components (pp. 51–107). New York, NY: Oxford University Press.

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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