Emotions and physiology

”

Moreover, the patient’s pulse and disposition are altered when mention is made of the person he loves, and especially when this occurs suddenly. It is possible in this way to ascertain whom he loves, when he will not reveal it himself.

The nature of the cure is this: let several names be pronounced, **repeating them many times,** and place your finger on the patient's pulse. When it varies by a large fluctuation and then returns to normal, and this is repeated thereafter, and is put to the test many times, then the name of the one he loves will be known.

”

– Ibn Sina (1025). *The canon of medicine*.

Mesulam, M.-M., & Perry, J. (1972). The diagnosis of love-sickness: Experimental psychophysiology without the polygraph. *Psychophysiology, 9*(5), 546–551, as cited by
Andreassi, J. (2007). *Psychophysiology: Human Behavior and Physiological Response* (5th Edition). New York, USA: Psychology Press.

Physiological measurement

In 1791, Luigi Galvani discovered that frog legs twitched when subjected to electrical current.

This led to the *frog galvanoscope*, a device to detect electricity.

With this, electrical currents were also found in human bodies.

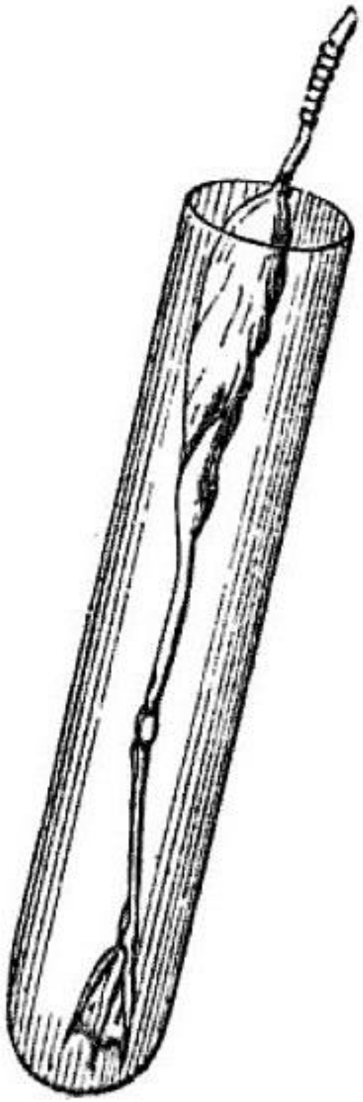
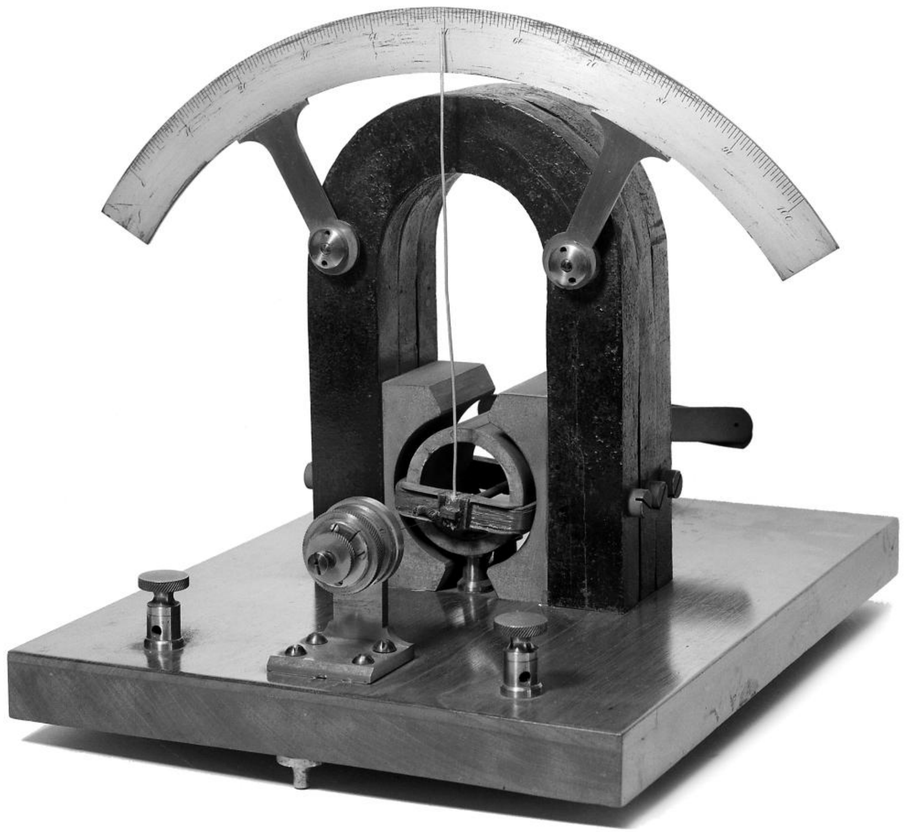


Illustration: Hogg, J. (1861). *Elements of experimental and natural philosophy* (p. 502). London, UK: Henry G. Bohn.

Physiological measurement

Richard Caton used a galvano*meter* to observe electrical impulses from the surface of living rabbit and monkey brains.

"… currents ... were found to be … influenced by stimulation of the ... retina by light."

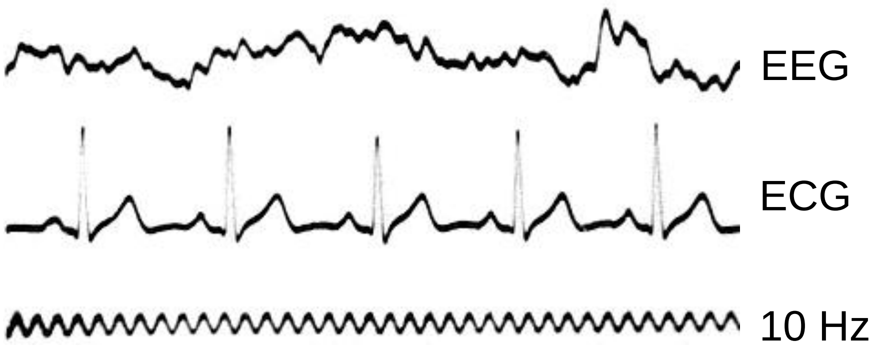


Caton, R. (1875). The electric currents of the brain. *British Medical Journal, 2*(765), 278.

Physiological measurement

In 1924, Hans Berger performed the first measures on a living human brain.

Later measurements revealed first indications that different intensities of mental activity led to visible changes in the recorded curves.

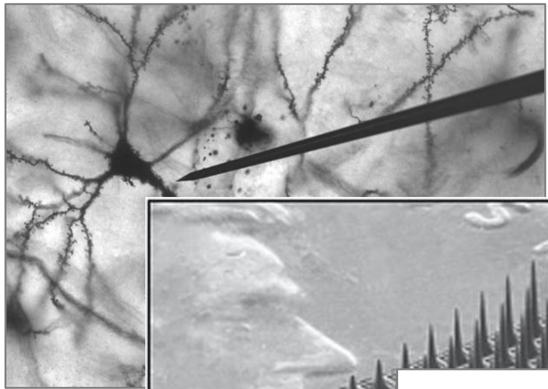


Berger, H. (1929). Über das Elektrenkephalogramm des Menschen. *Archiv für Psychiatrie und Nervenkrankheiten, 87*, 527–570.

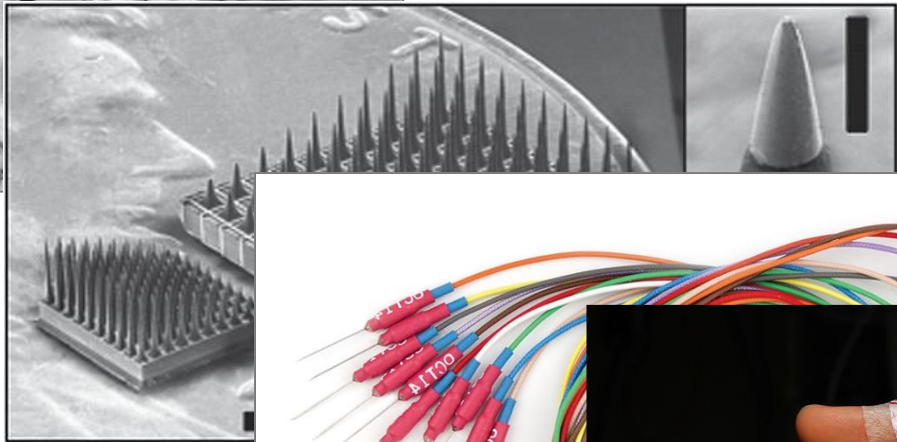
Measuring (electro)physiological parameters

Types of electrodes

Microelectrodes

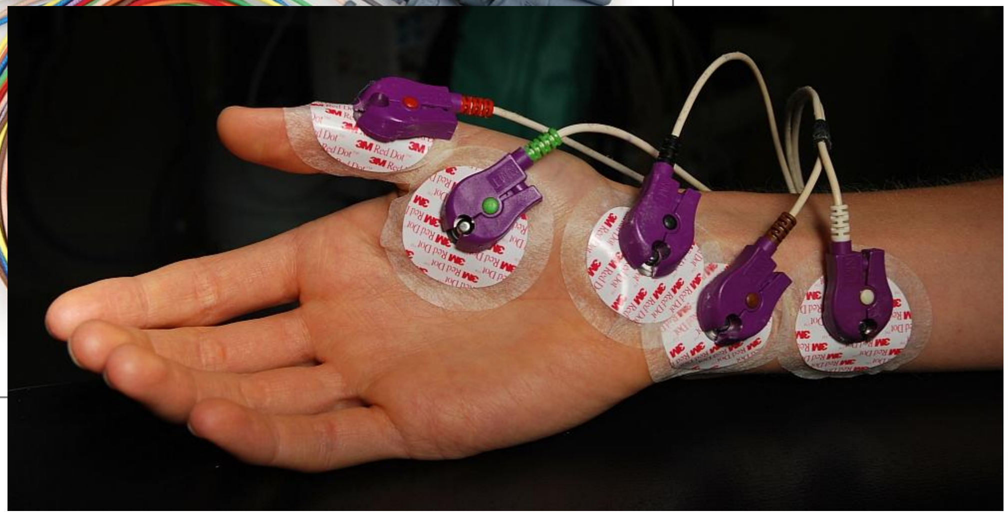


Microelectrode arrays

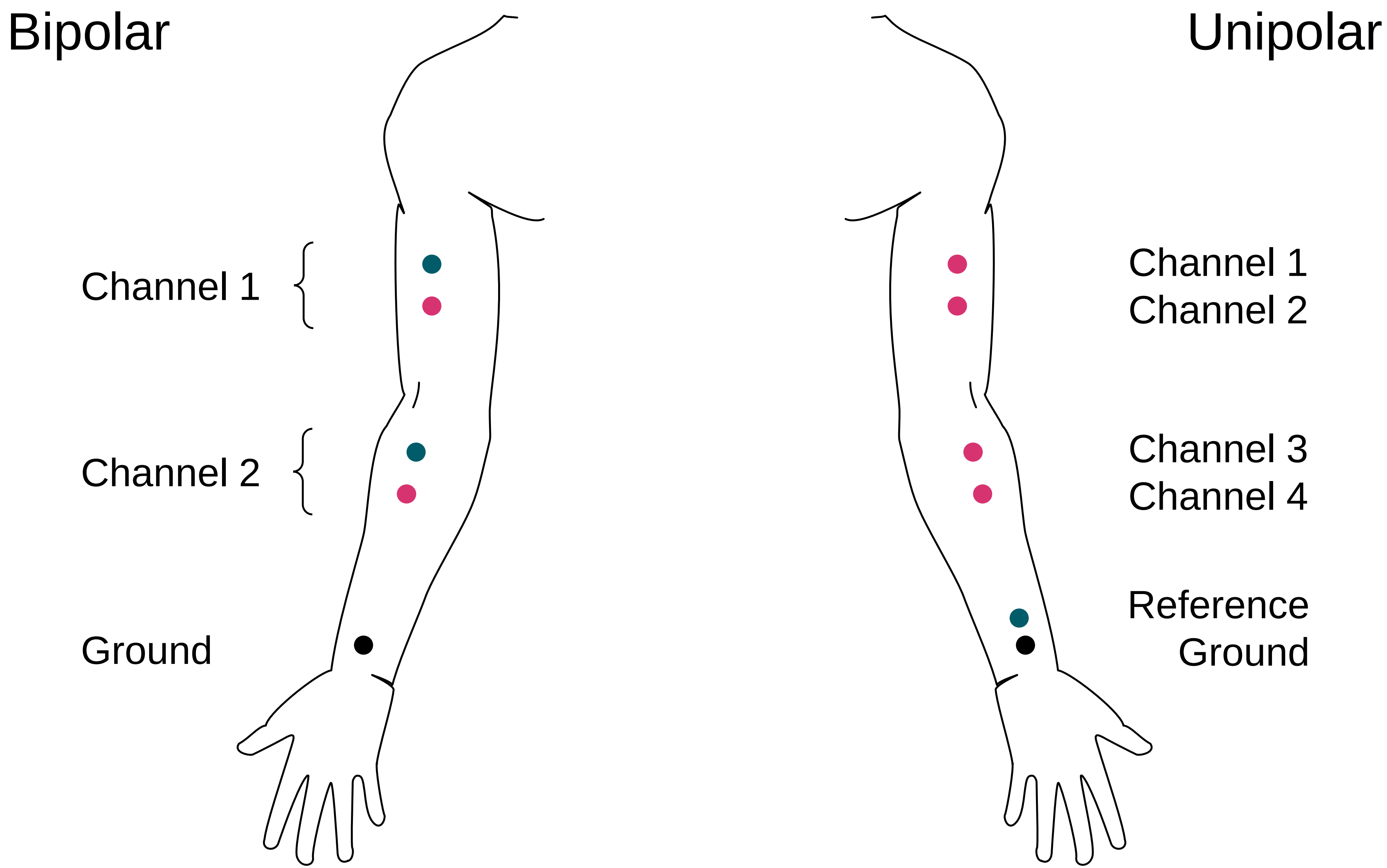


Subdermal electrodes

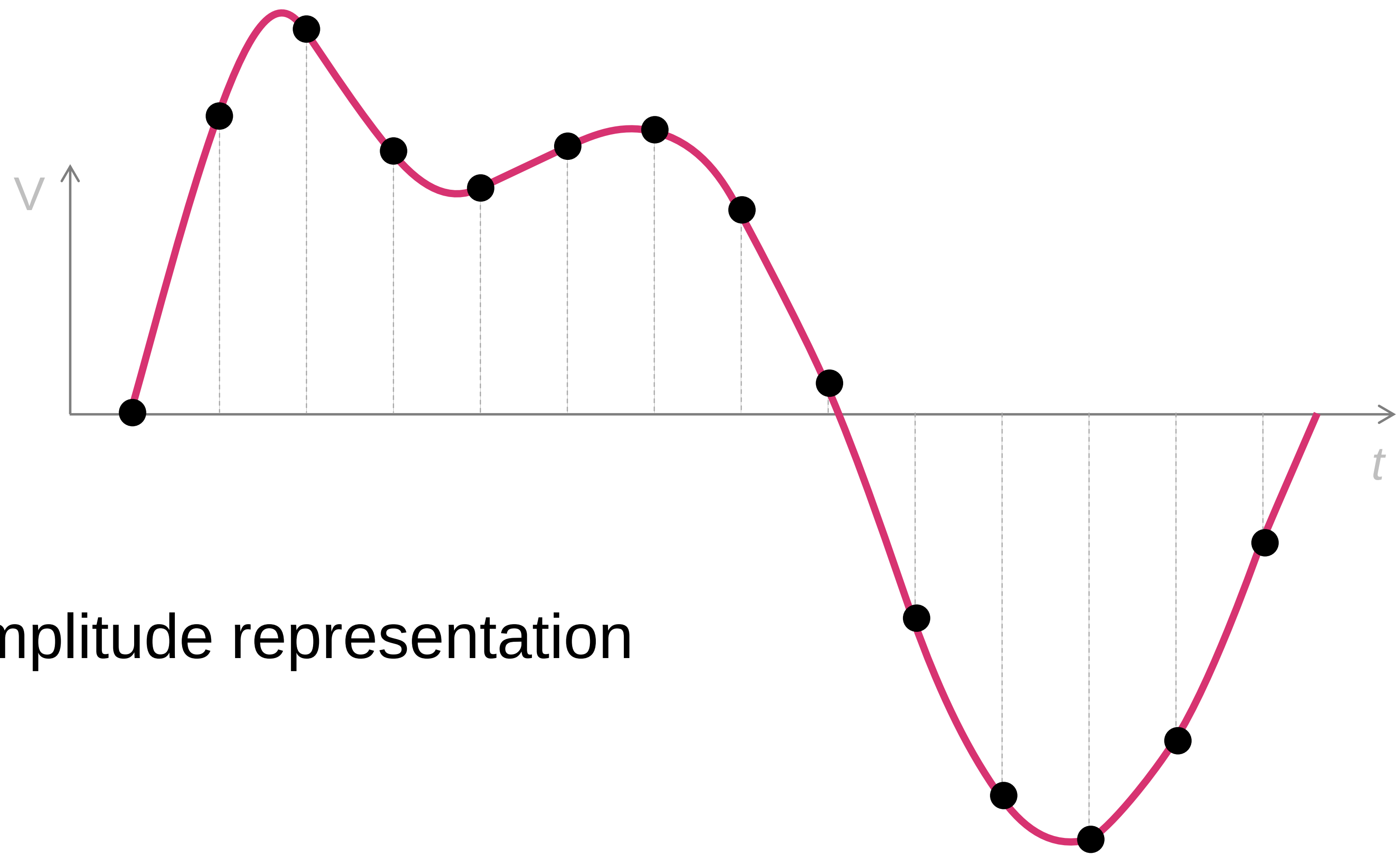
Surface electrodes



Bipolar and unipolar recording techniques



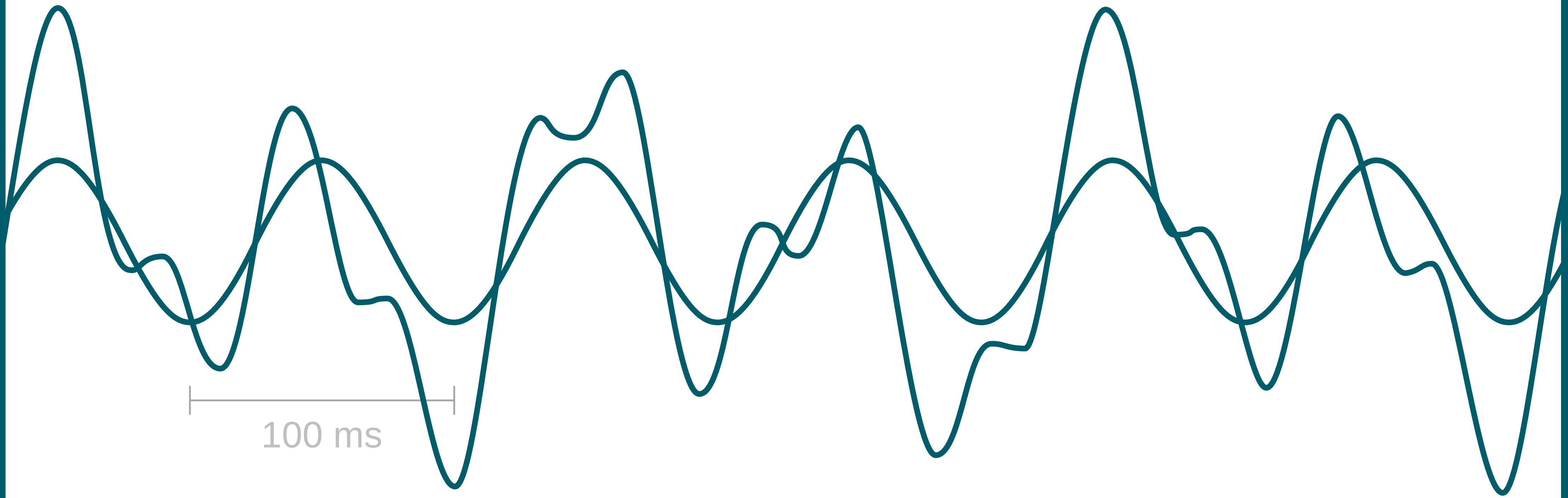
Temporal signal properties



Time-amplitude representation

Spectral signal properties

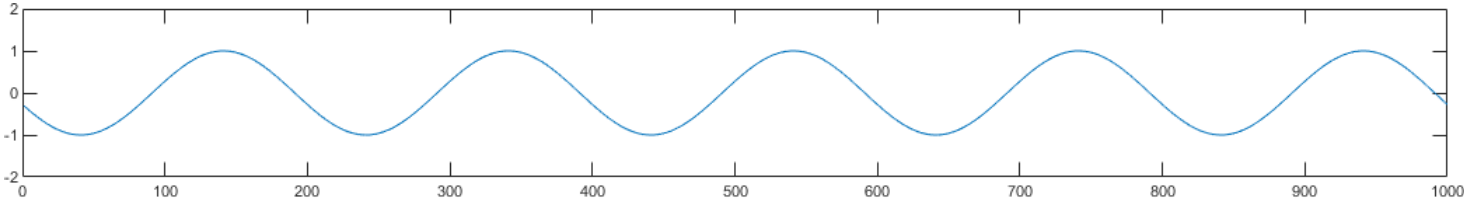
Time-varying signals can be very complex.



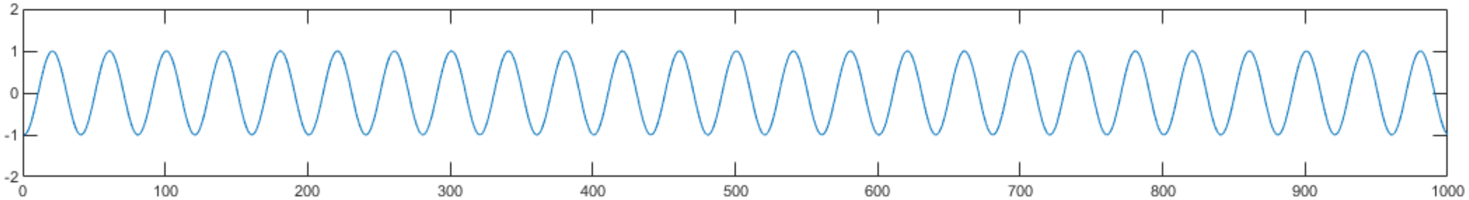
It is sometimes easier to look at them as frequencies.

Mixing frequencies

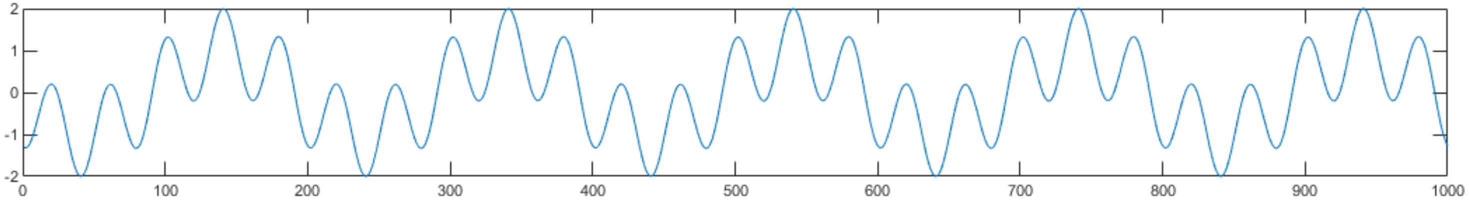
5 Hz



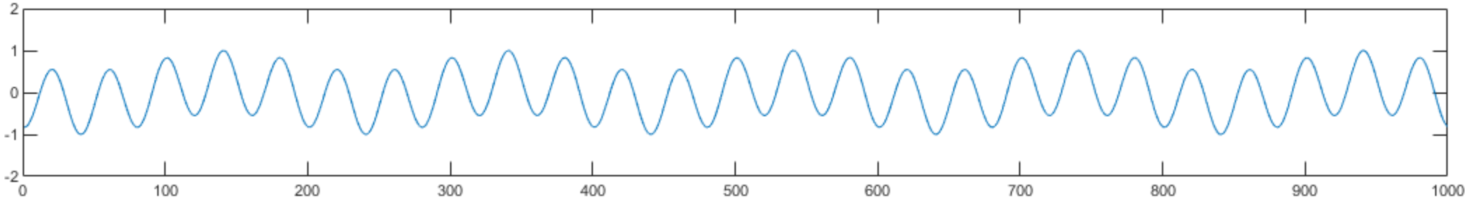
25 Hz



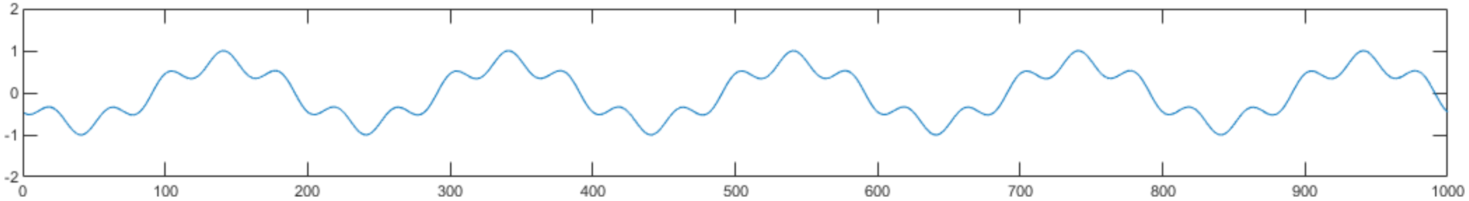
5 + 25



¼(5) + ¾(25)

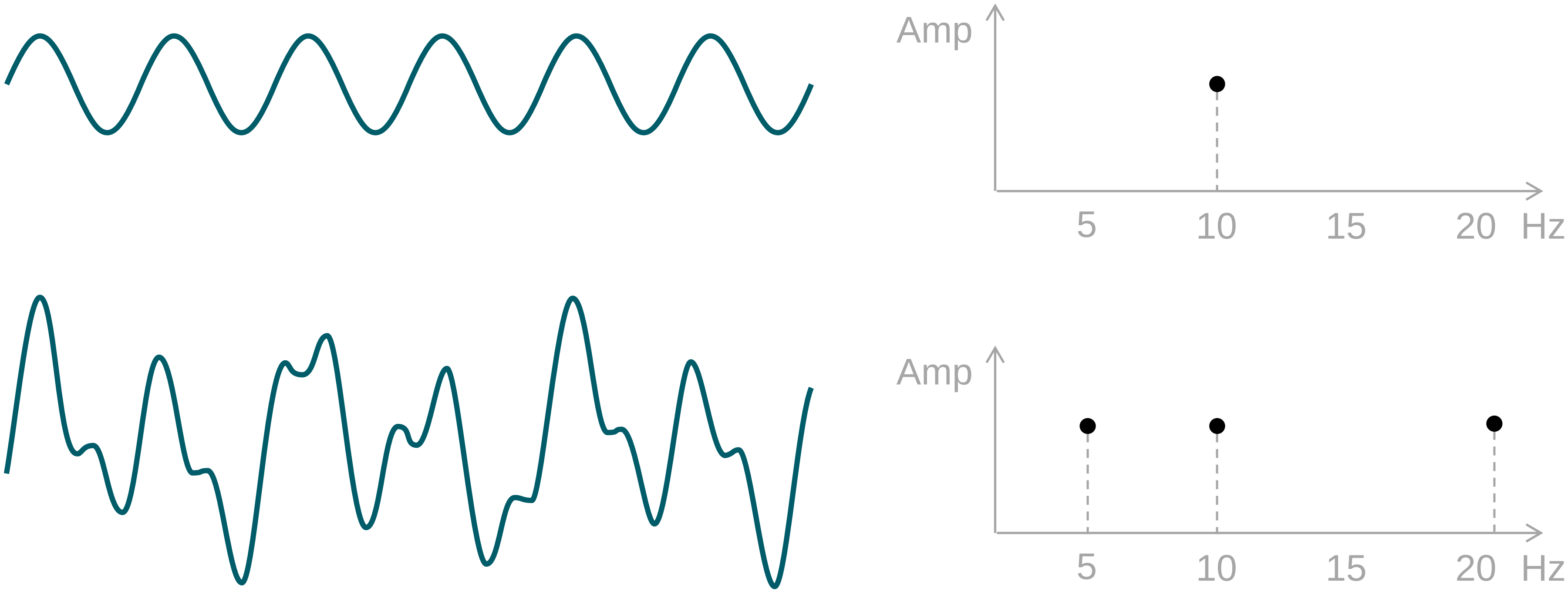


¾(5) + ¼(25)



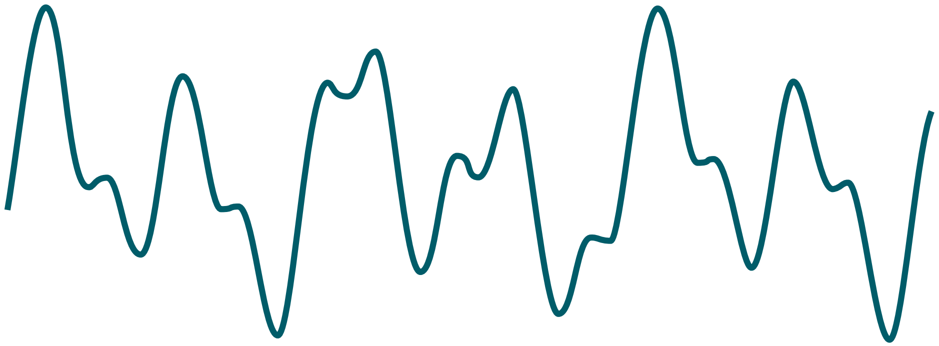
Spectral analysis

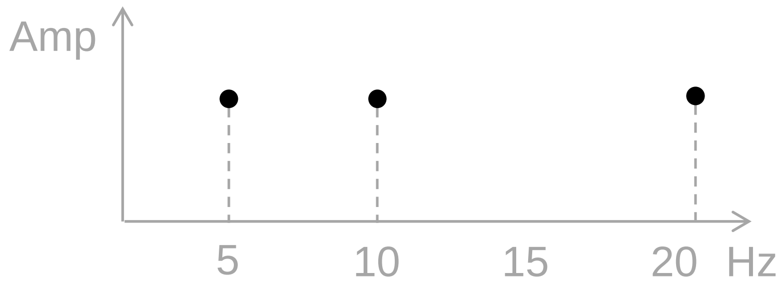
Frequency-amplitude representation

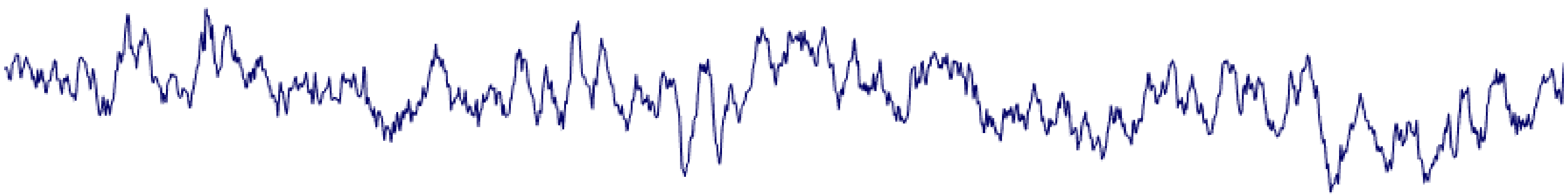


Spectral analysis

Real data is more complex!

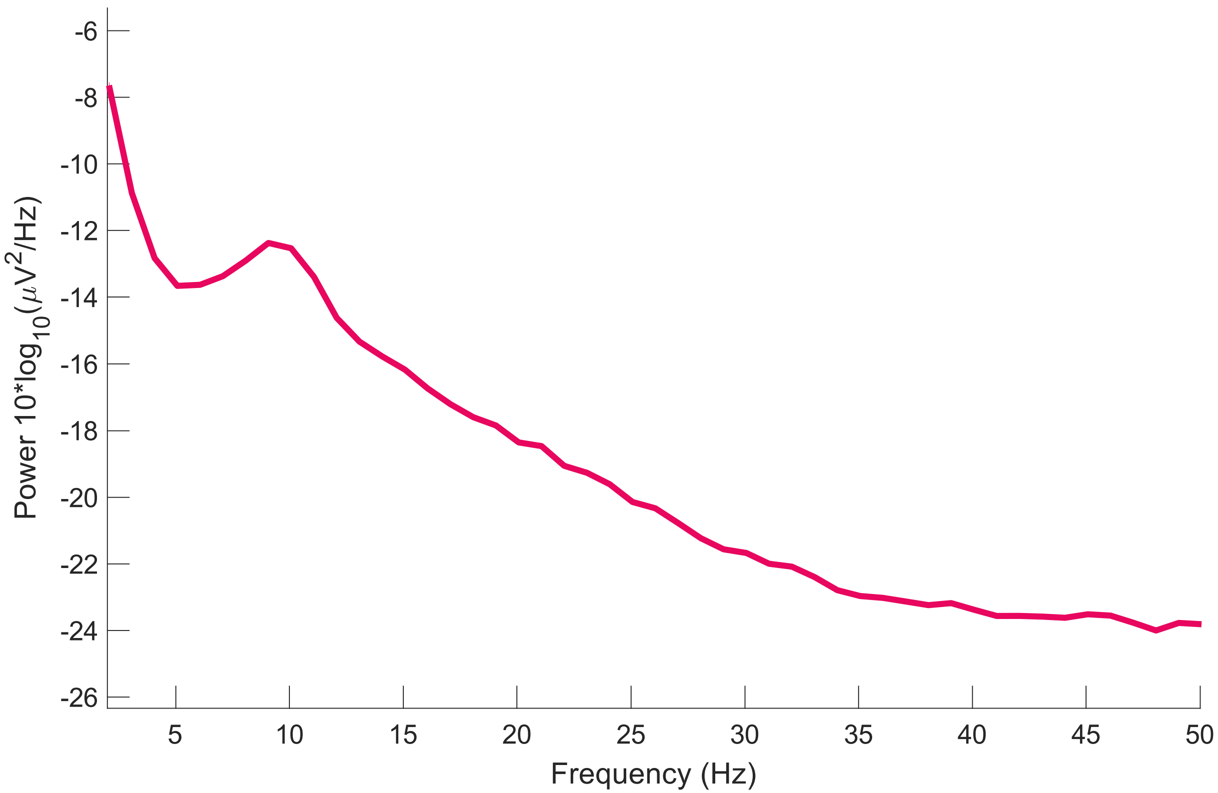






Frequency spectrum

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

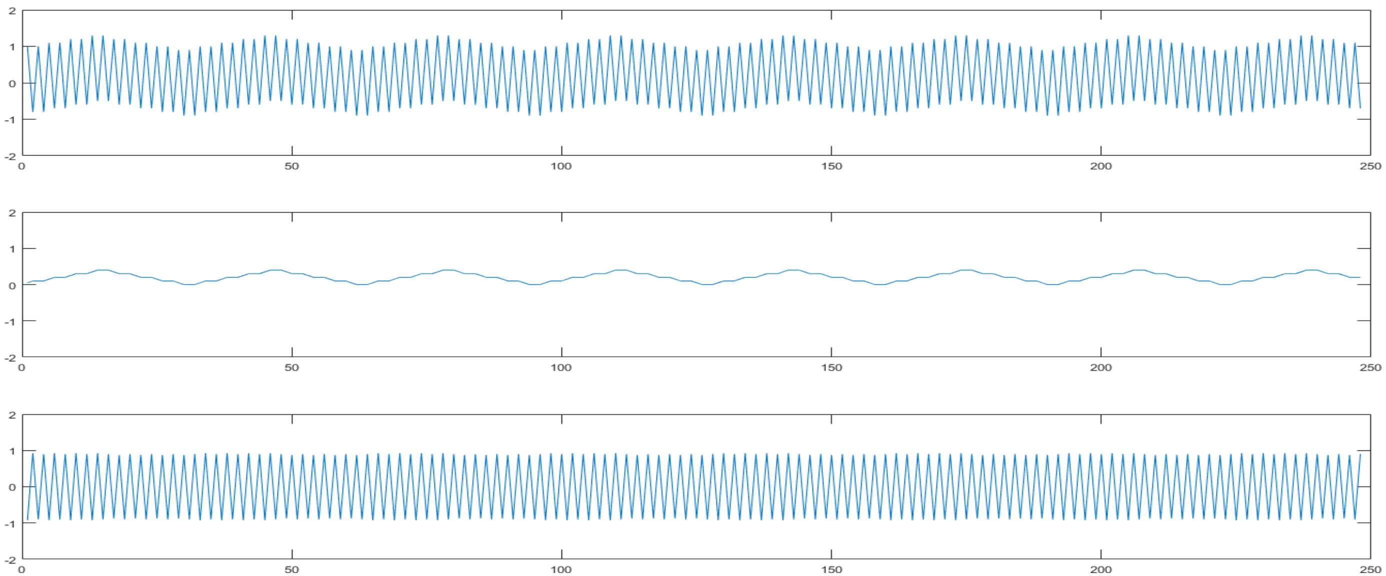


Digital filters

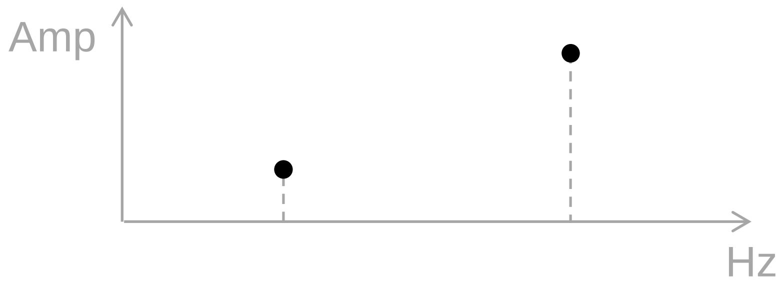
Recorded signal with more high-frequency power

Low-pass filtered

High-pass filtered



Filters and other transformations allow us to investigate the power of specific frequencies.



Artefacts

Specific focus of psychophysiological experimentation is on controlling EVs known as artefacts.

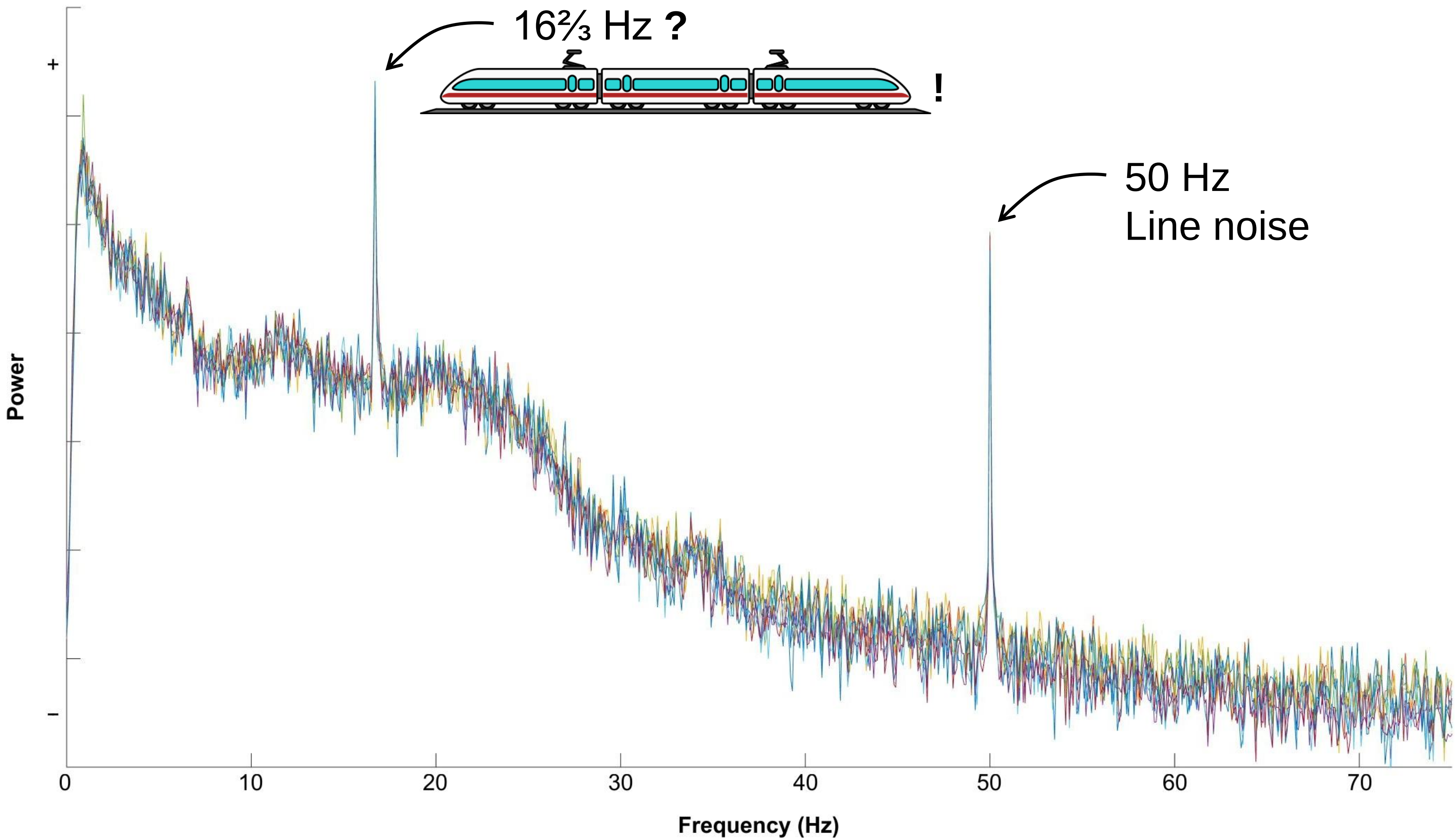
“Artefacts” in the recording are those signals that do not represent the biosignal of interest.

Artefacts can be of

- external (mechanical, environmental), or
- internal (biological)

origin.

External artefacts: Example



Mechanical artefacts

Mechanical artefacts are caused by movement of the equipment.

The movement of an electrode across the skin can lead to differences in resistance, and thus differences in the recorded signal.

The movement of electrode cables suspended in the air can lead to changes in their position in electromagnetic fields, thus causing differences in the recorded signal.

Controlling external artefacts

Ahead of time:

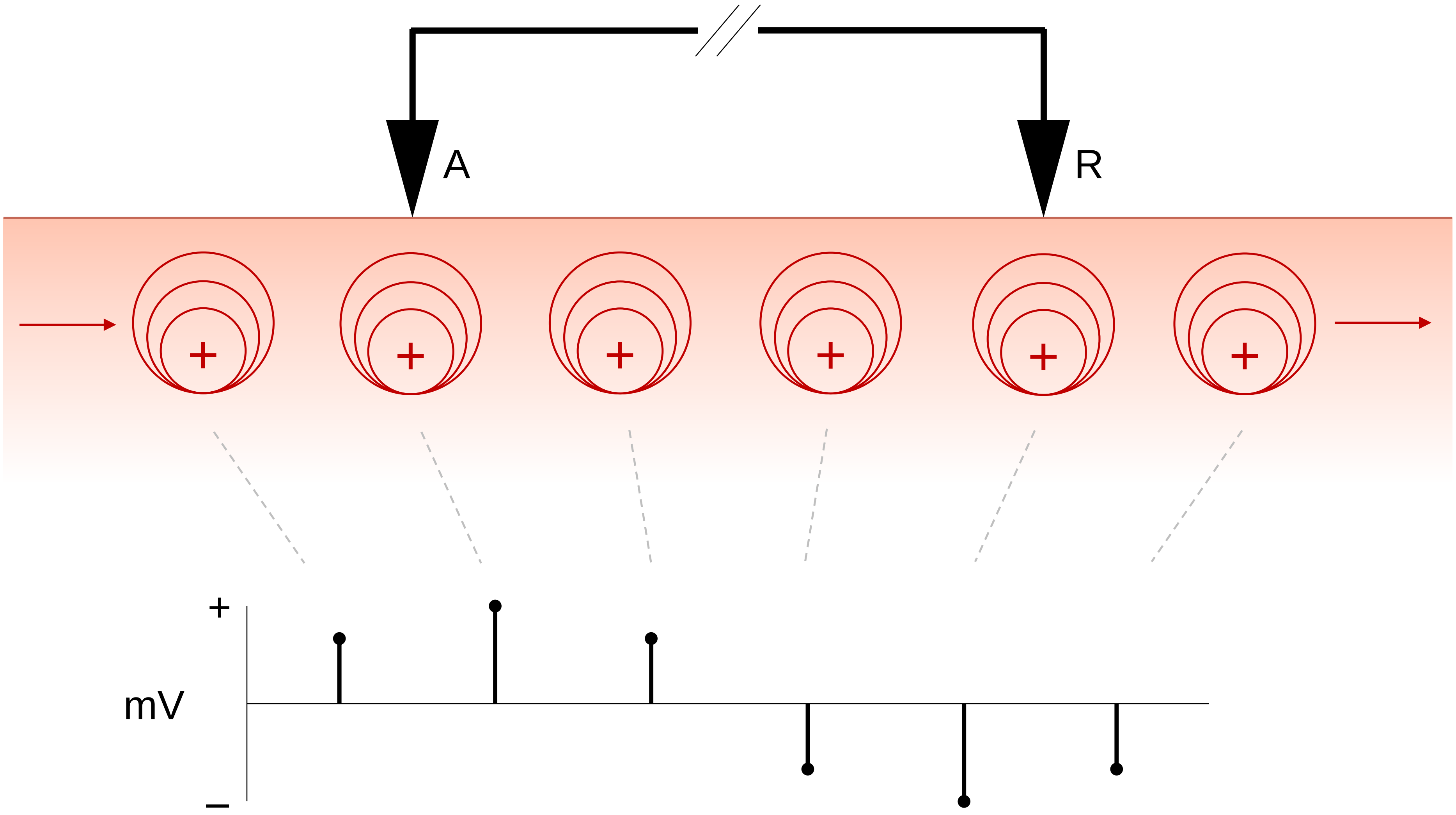
- Shield the room and the equipment.
- Use electrodes with pre-amplifiers.
- Have participants be stationary and comfortable.

Post hoc:

- Preprocess data to remove known artefacts.
- Discard contaminated data.

Electromyography

Origin of EMG: Muscle fiber action potentials



Motor unit potentials

A motor unit potential (MUP) refers to the sum of all muscle fiber action potentials of a single motor unit. This is what EMG measures.

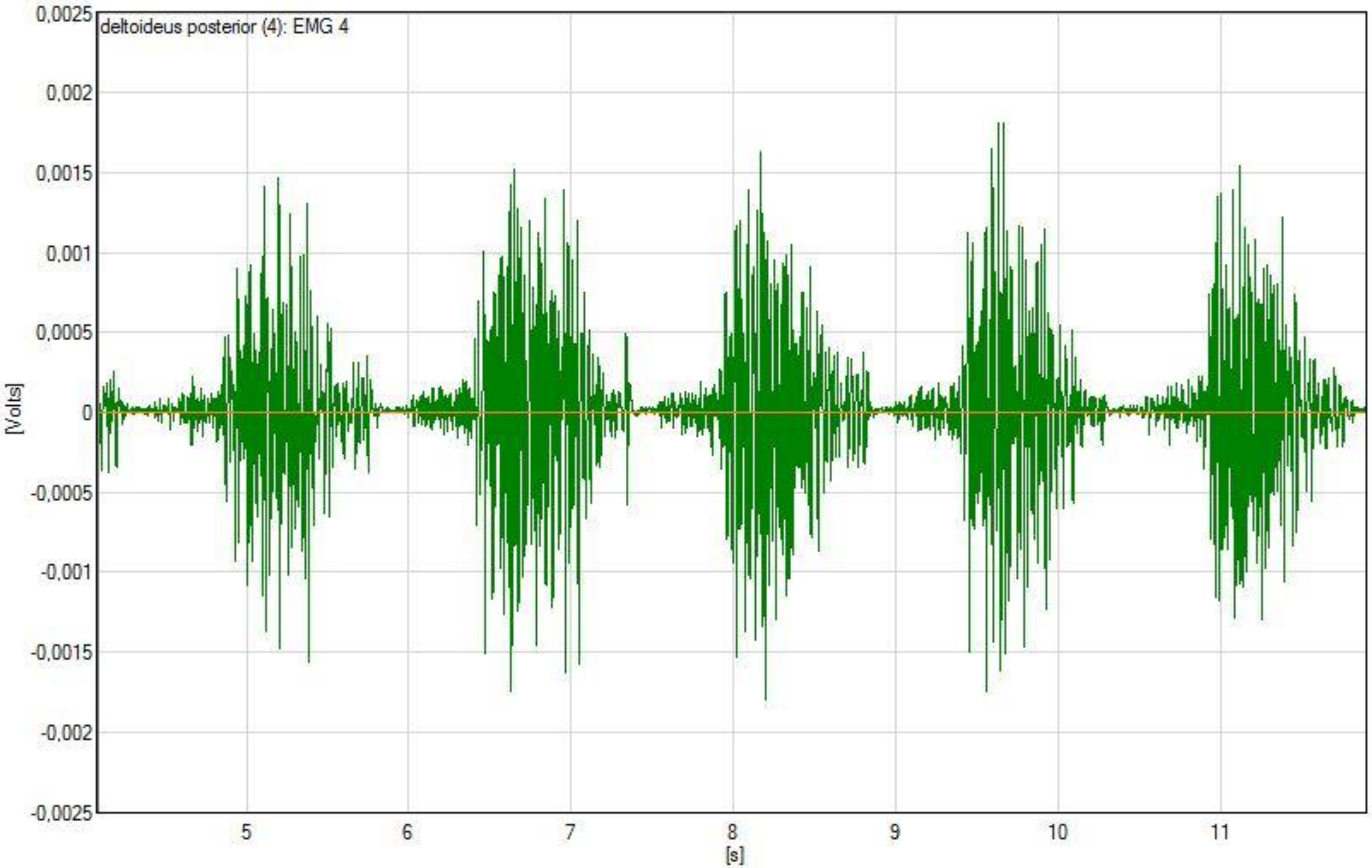
The measured signal is thus a function of

- the number of detected active motor units, and
- the rate at which they are firing.

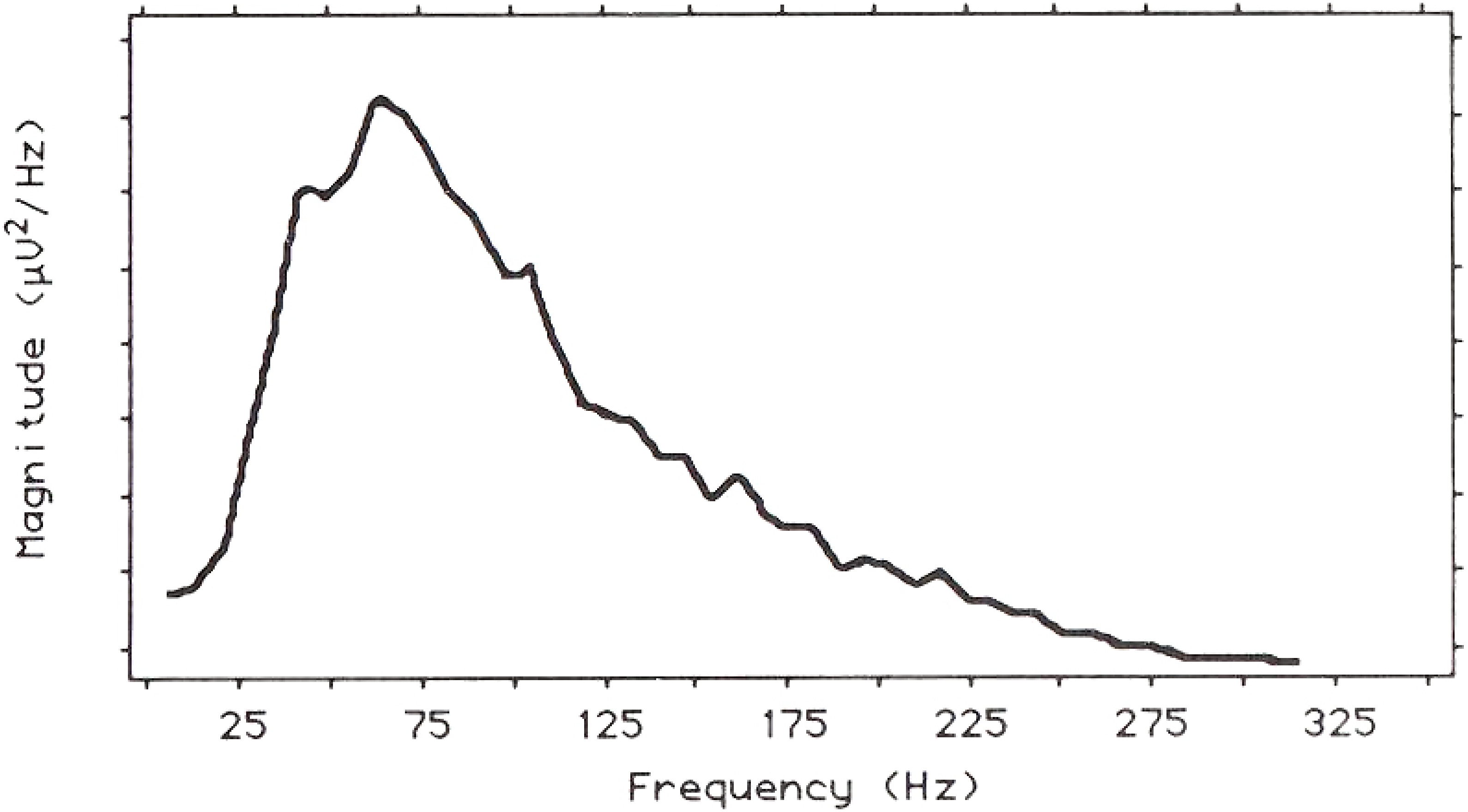
Multiple motor units each firing at around a maximum of 50 Hz, but not all firing at the same time, can add up to much higher frequencies.

This is why muscle activity is often broadband signal.

The EMG signal: Raw

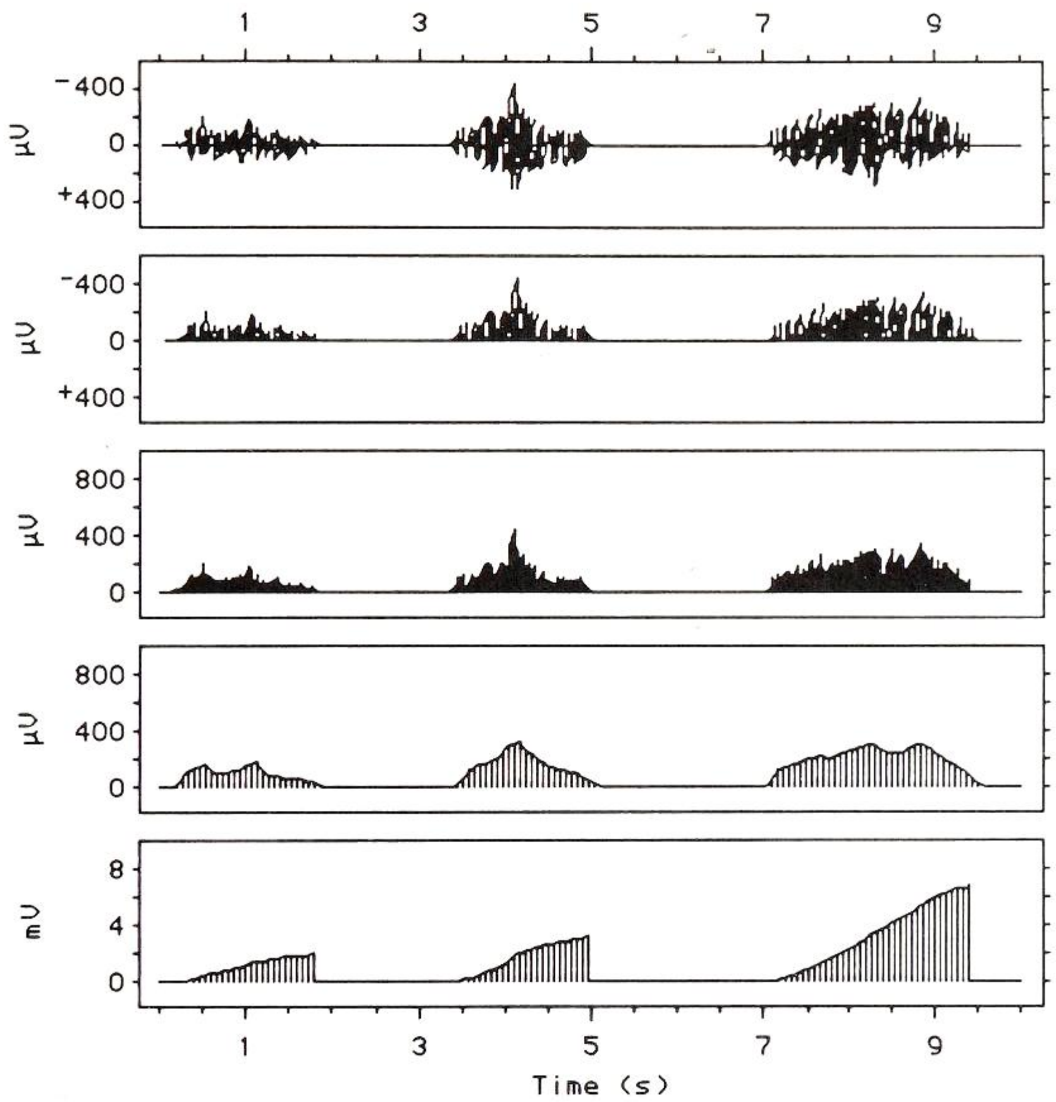


The EMG signal: Spectrum



Cacioppo, J. T. & Tassinary, Louis G. (1990). Principles of psychophysiology: Physical, social, and inferential elements. Cambridge, UK: Cambridge University Press.

EMG processing

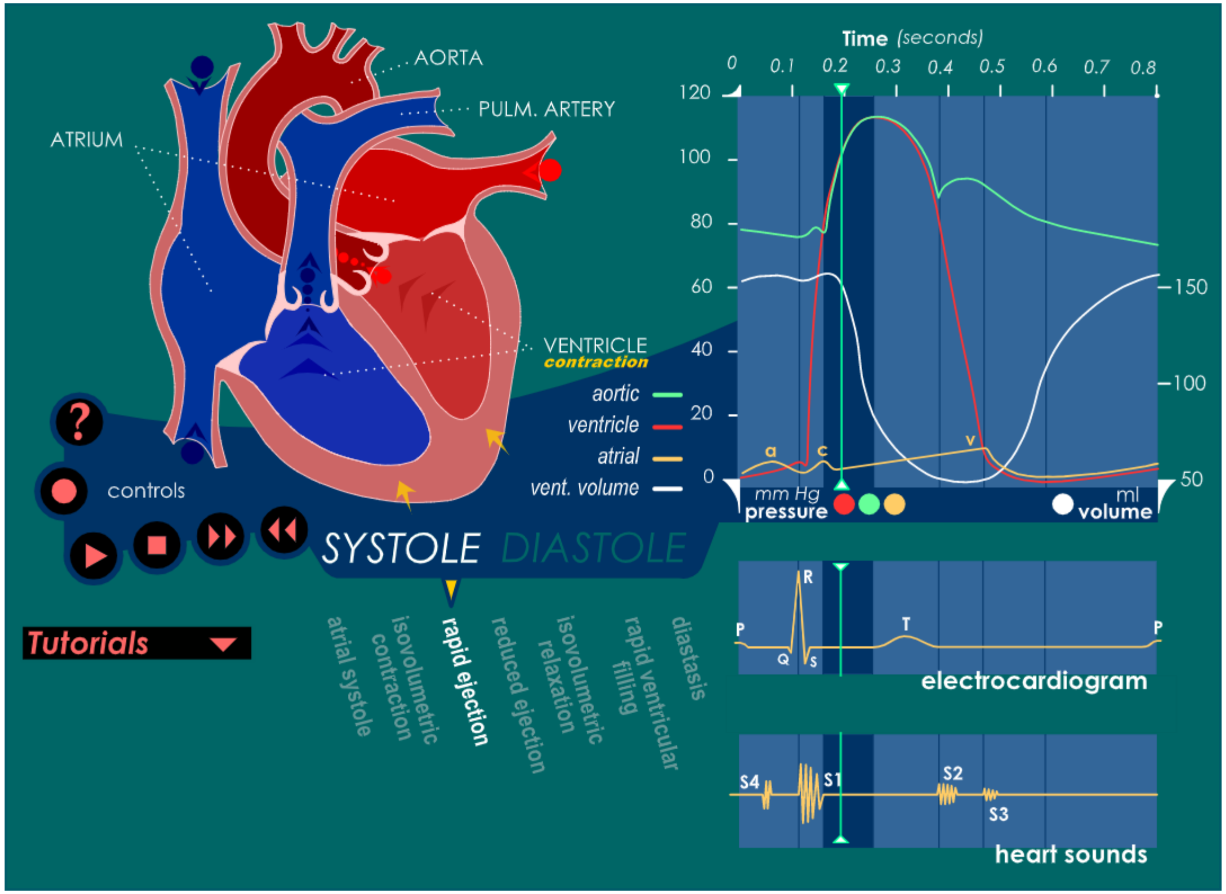


1. Raw signal
2. Rectification
   - Half-wave: Only retain positive samples
   - Full-wave: take absolute values
3. Smoothing
4. Integration

Figure: Cacioppo, J. T. & Tassinary, Louis G. (1990). Principles of psychophysiology: Physical, social, and inferential elements. Cambridge, UK: Cambridge University Press.

Electrocardiography

Interactive Wiggers diagram



https://library.med.utah.edu/kw/pharm/hyperheart

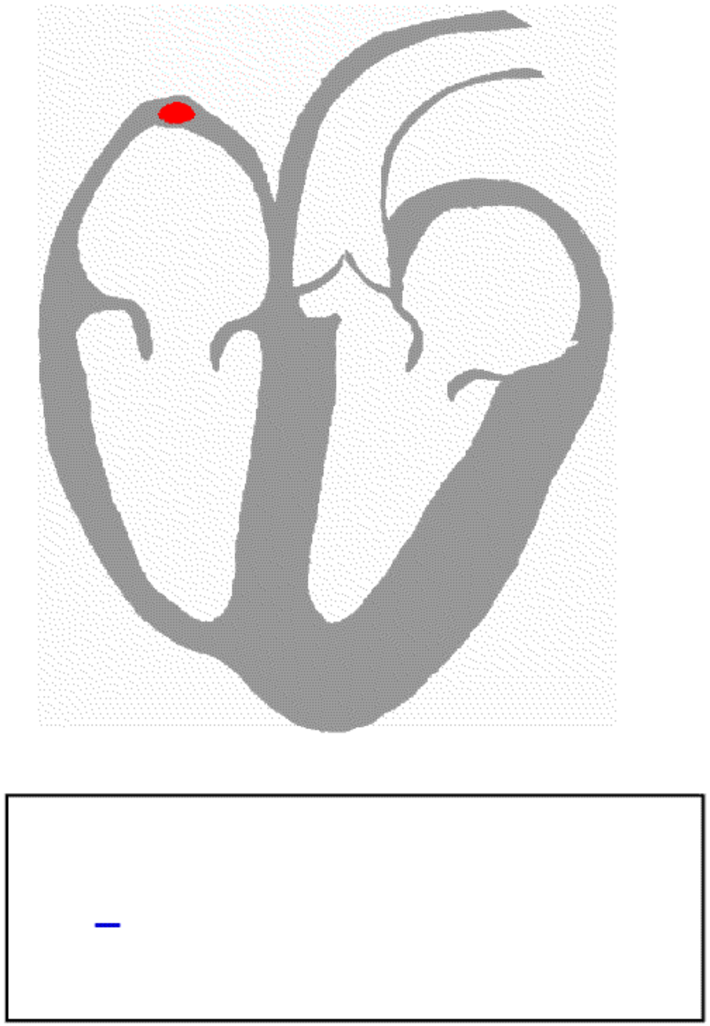
Heart rate

The SA node is the primary pacemaker, with the AV node yoked to its **sinus rhythm**.

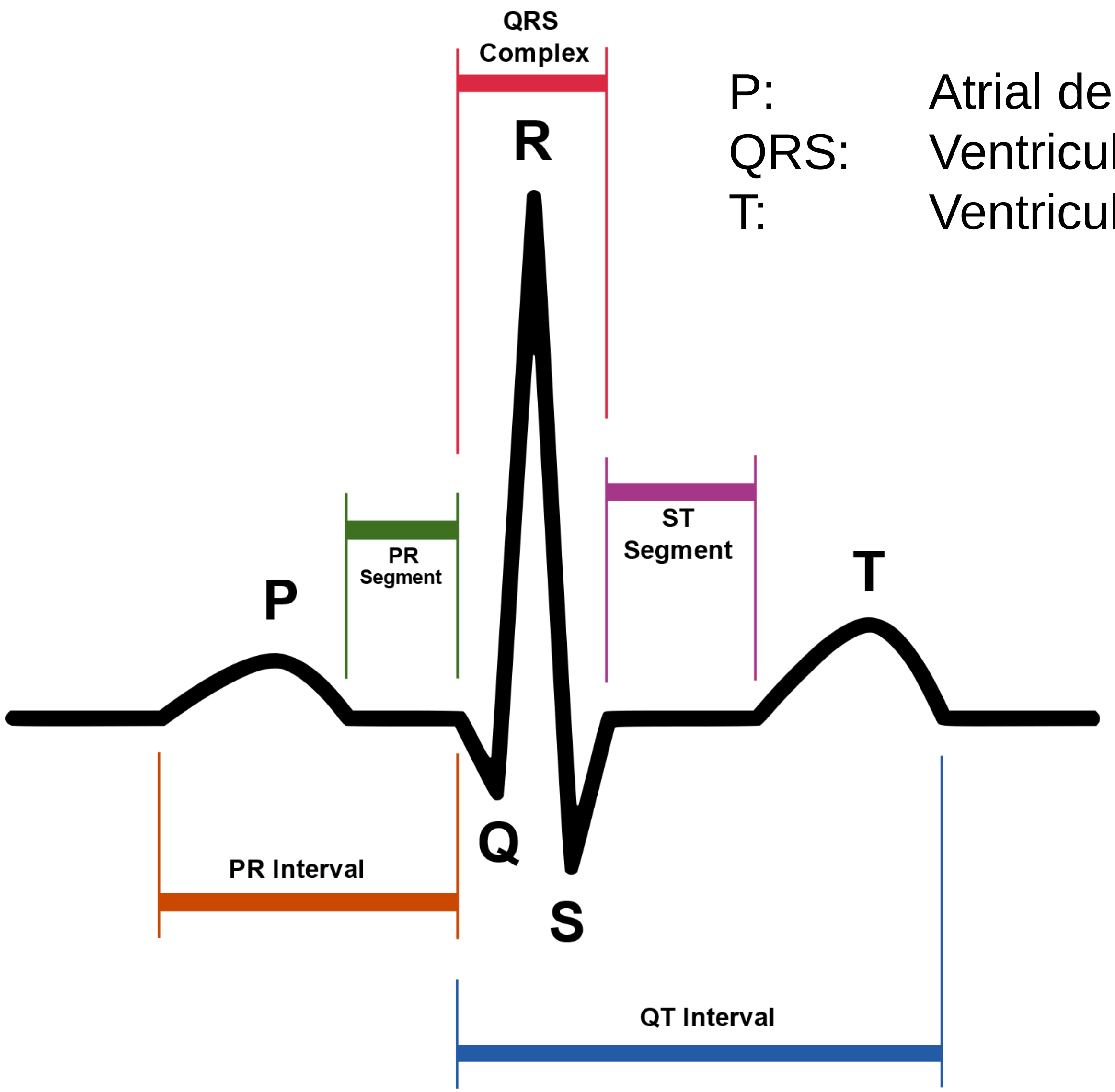
The SA node has an intrinsic rhythmicity of about 100 bpm; the AV node of about 40-60 bpm, the Bundle of His 20-40. The fastest available rhythm dominates the others.

A denervated heart would beat on its own at around 100 bpm. The autonomous nervous system can modulate the cardiac autorhytmicity, both to slow it down (parasympathetic) and to speed it up (sympathetic) as needed.

Neural conduction and the ECG



Peaks and intervals



P: Atrial depolarization
QRS: Ventricular depolarization
T: Ventricular repolarisation

Figure by Agateller (Anthony Atkielski)/atom is in the public domain

Heart rate

Heart rate (HR) is the number of contractions (beats) of a heart per minute (bpm).

Easily operationalised from an ECG as the number of R peaks per minute.

HR responds to almost all physical and psychological changes: e.g., pain and fear increase, whereas relaxation and attention decrease HR; but even circadian and menstrual cycles can influence HR.

This bidirectionality is an advantage for psychophysiology.

Slow changes can be recorded by taking e.g. HR measurements per minute.

Heart rate variability

Changes in HR can also be operationalised as another metric in itself: **heart rate variability** (HRV).

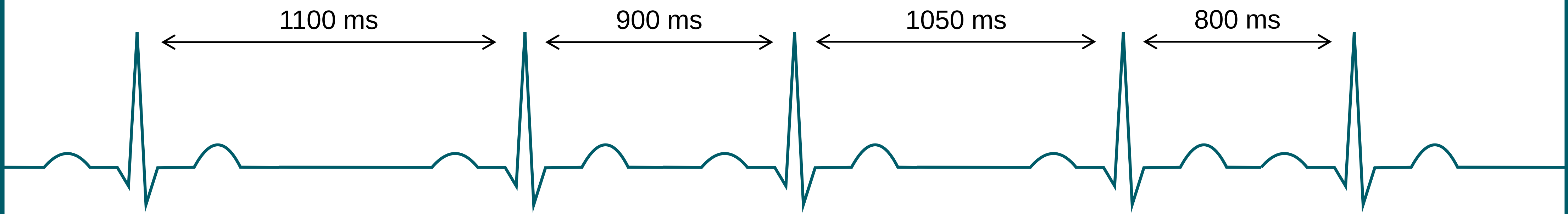
The inter-beat interval (IBI) is the distance between two successive R peaks.

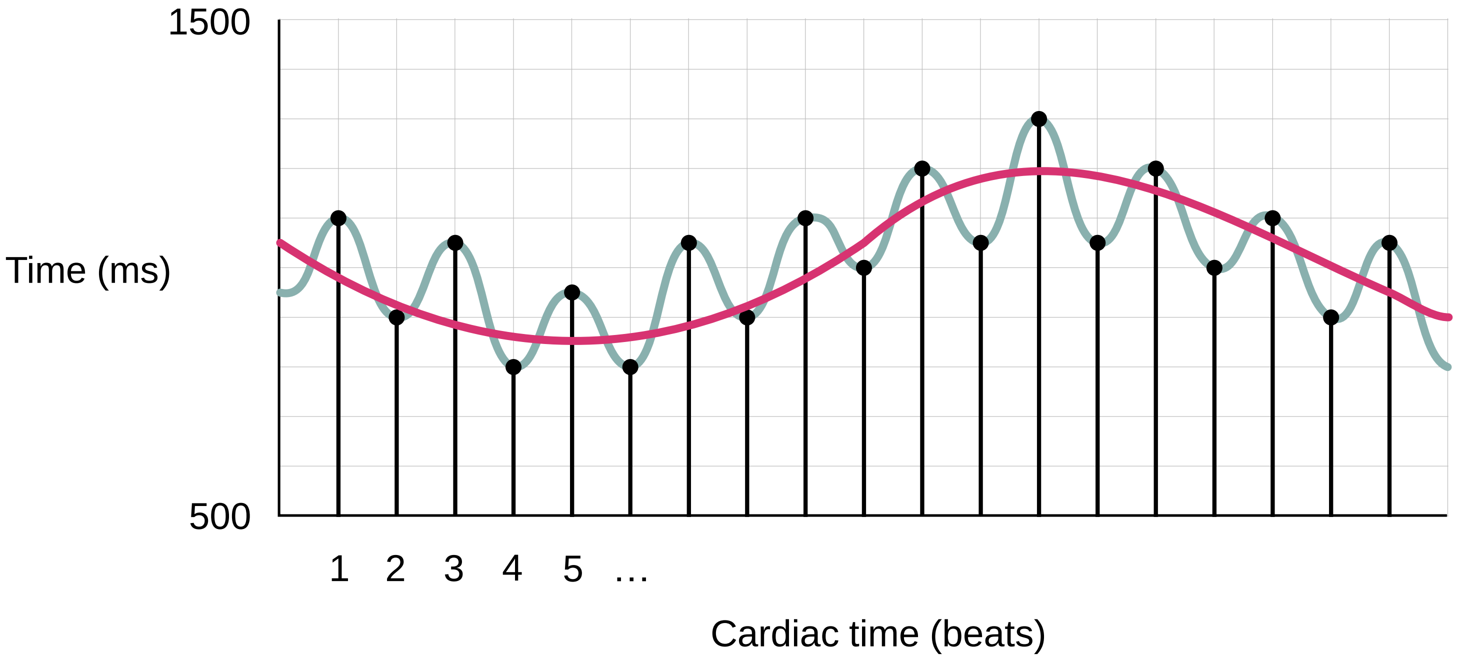
Many metrics can be constructed from this, e.g. arithmetic means, standard deviations, *RMSSD* = $\sum_{i=1}^{N-1} \frac{(IBI_{i+1} - IBI_i)^2}{N-1}$, proportion of successive intervals above a threshold, …

RMSSD (root mean square of successive differences) is often preferred for statistical reasons.

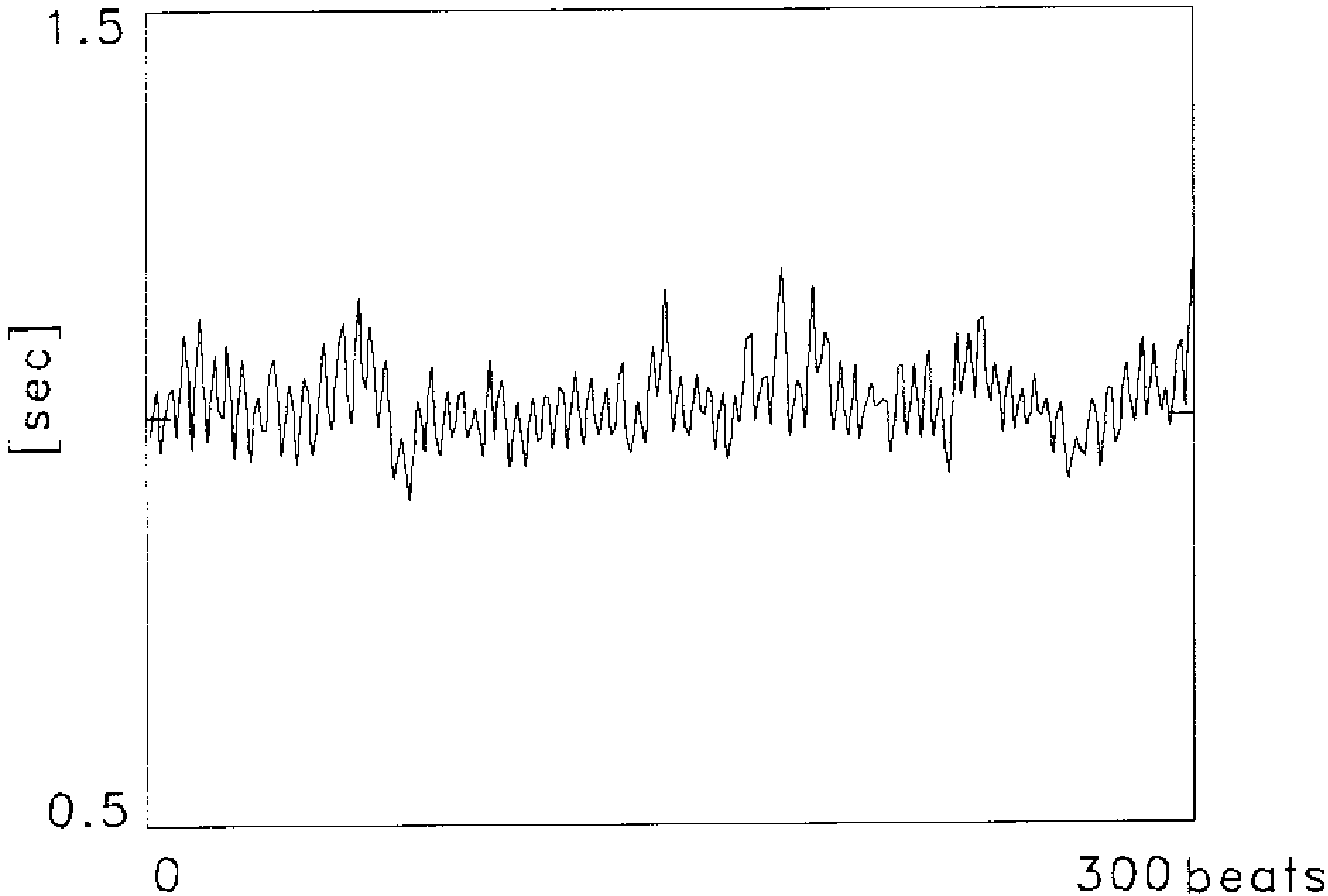
HRV also allows spectral analyses.

Spectral analysis: Cardiac time



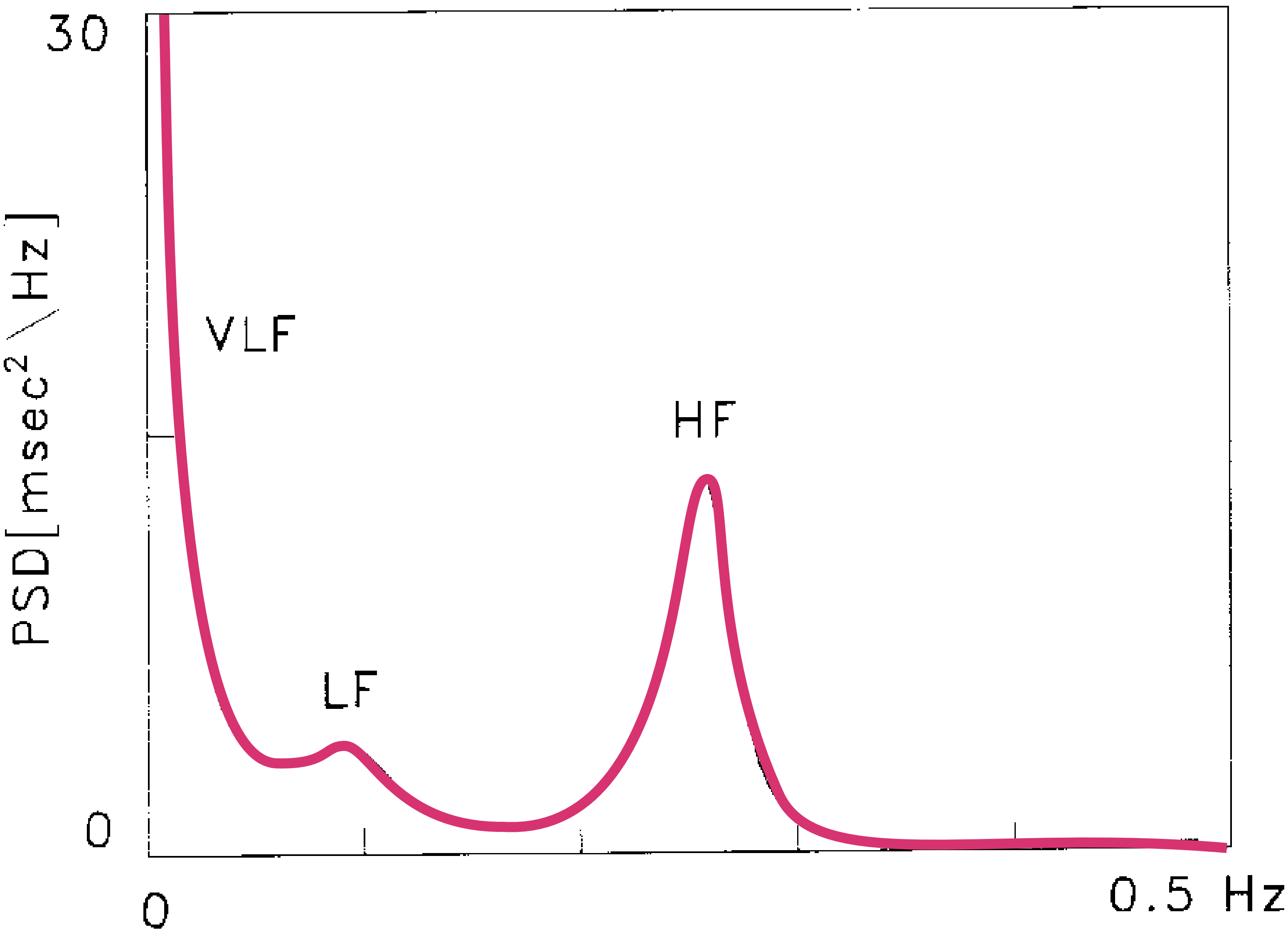


Spectral analysis: Processed signal



Lombardi, F. (1997). Spectral Analysis of Heart Rate Variability. *Cardiac Electrophysiology Review, 3*, 335-337.

Spectral analysis



Lombardi, F. (1997). Spectral Analysis of Heart Rate Variability. *Cardiac Electrophysiology Review, 3*, 335-337.

Interpretation

Very Low Frequency (0 - 0,04 Hz):

- Circadian rhythm, metabolism, thermoregulation

Low Frequency (0,04 - 0,15 Hz):

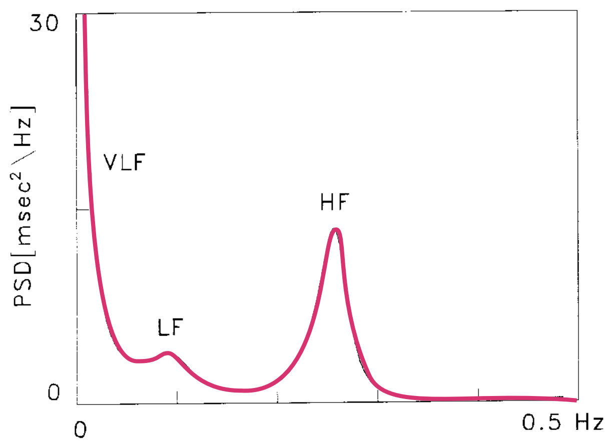
- Blood pressure regulation
- Para- and (mostly) sympathetic modulation

High Frequency (0,15 - 0,40 Hz)

- Respiratory sinus arrhythmia
- Parasympathetic modulation

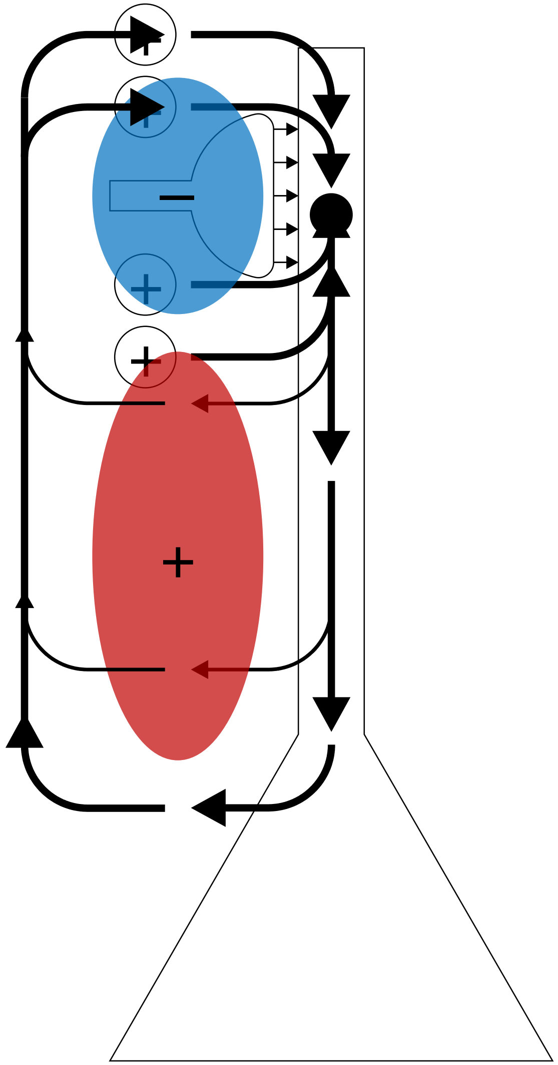
LF / HF Ratio

- Balance of para-/sympathetic activity

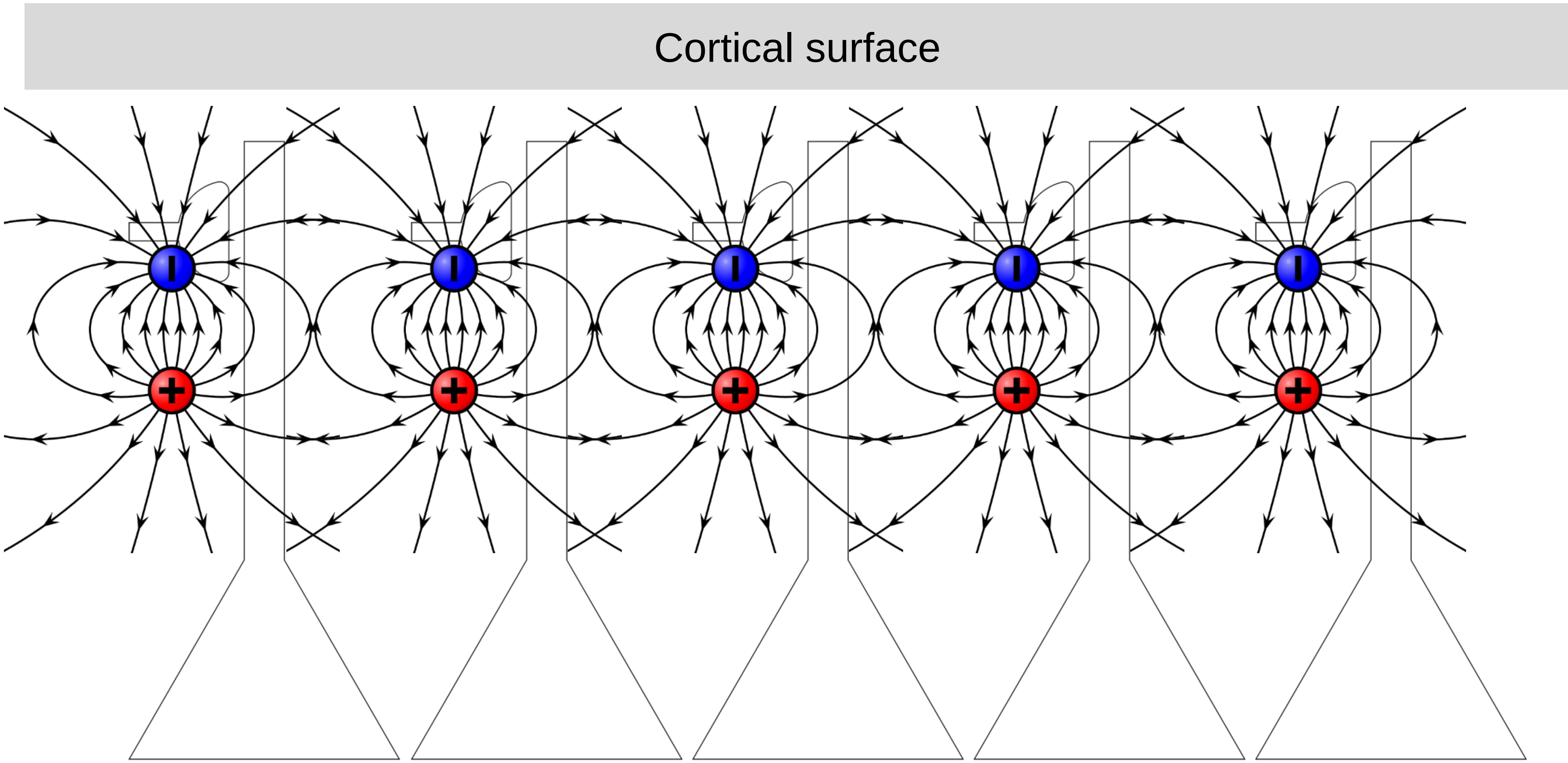


Electroencephalography

Cortical pyramidal cells



Cortical pyramidal cells

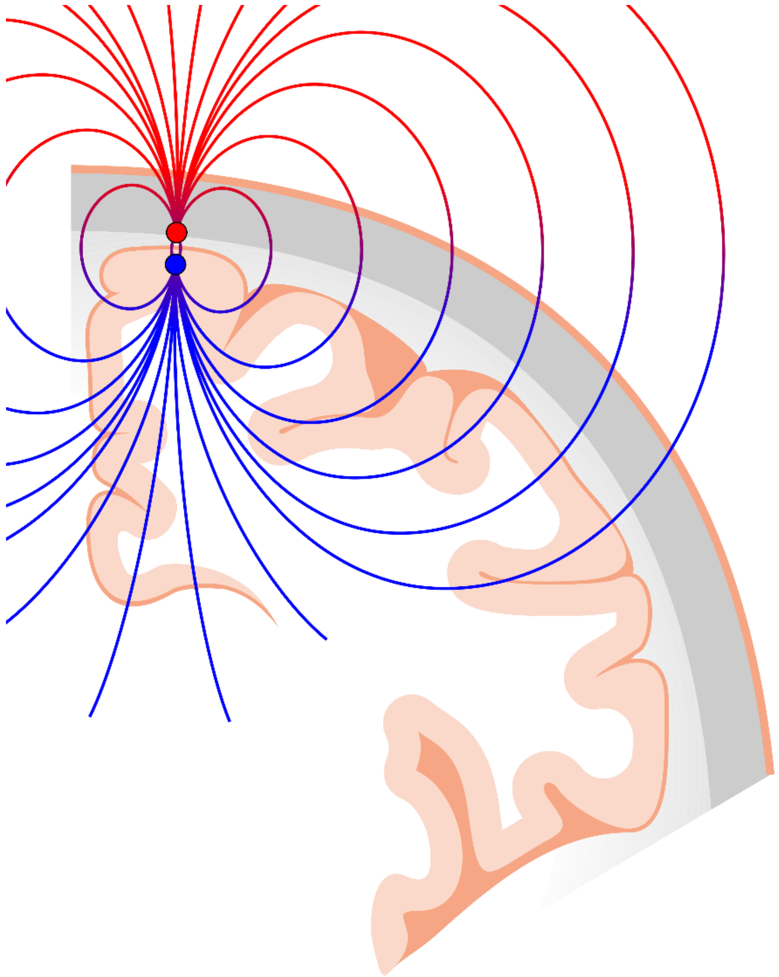


Physiological origins of EEG

A single EEG electrode records the activity of *at least* 10 million neurons, possibly up to 1000 million.

EEG, therefore, has relatively low spatial resolution.

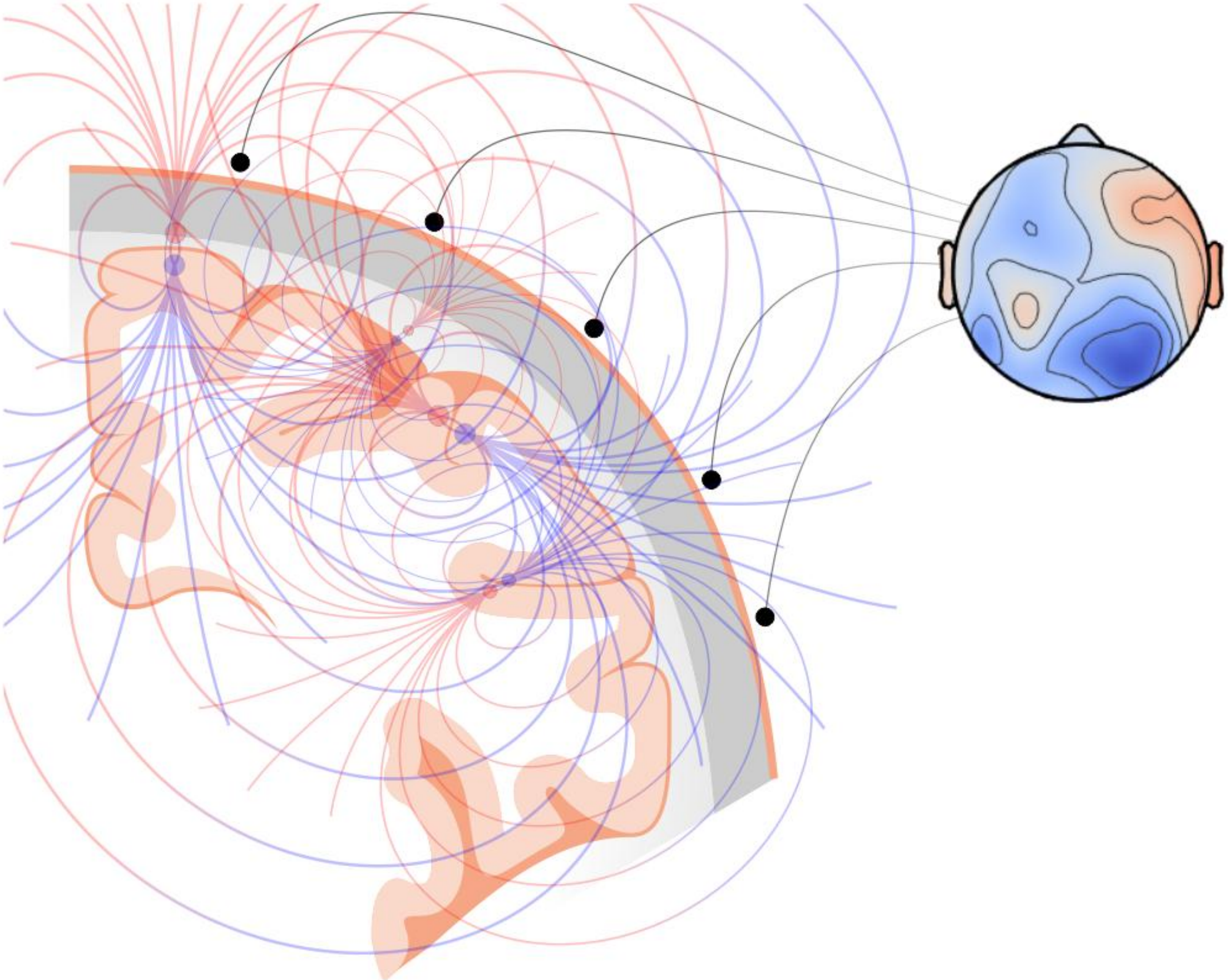
This is due to the previous requirements, as well as volume conduction.



Numbers from

Nunez, P. L., & Srinivasan, R. (2006). *Electric fields of the brain: the neurophysics of EEG*. New York, NY, USA: Oxford University Press.

Volume conduction



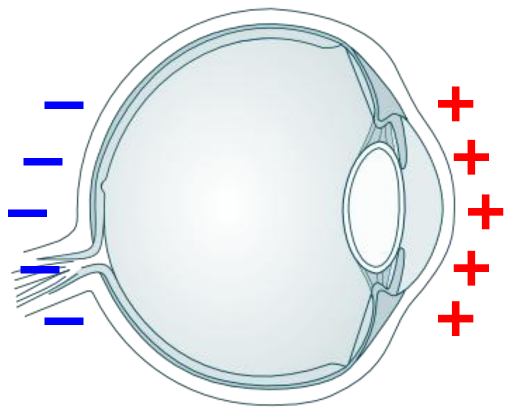
Artefacts

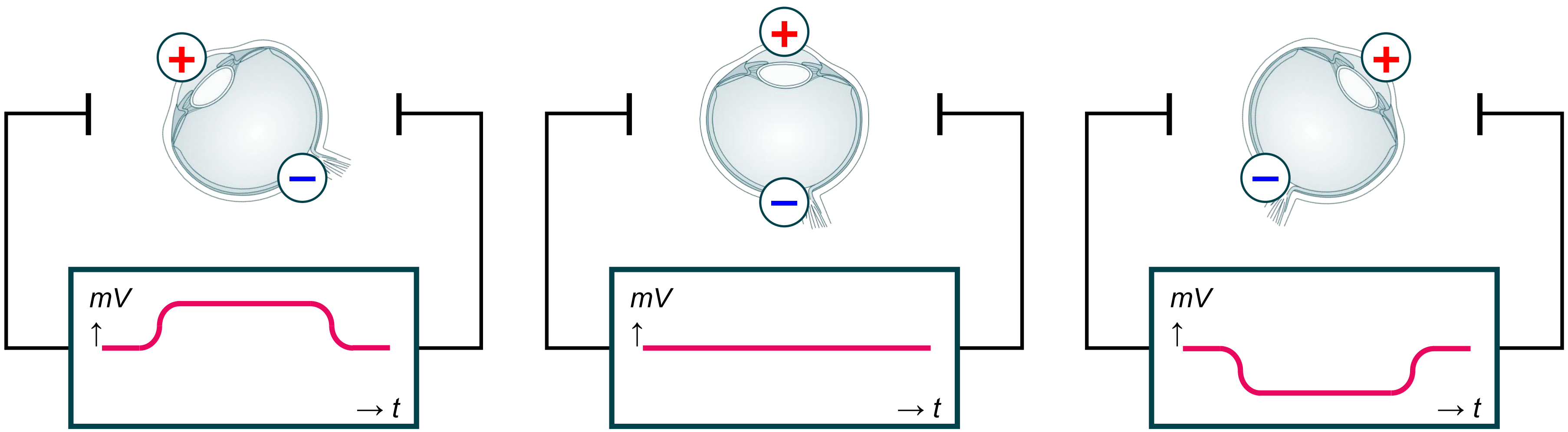
Aside from the general artefacts already discussed, e.g.

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

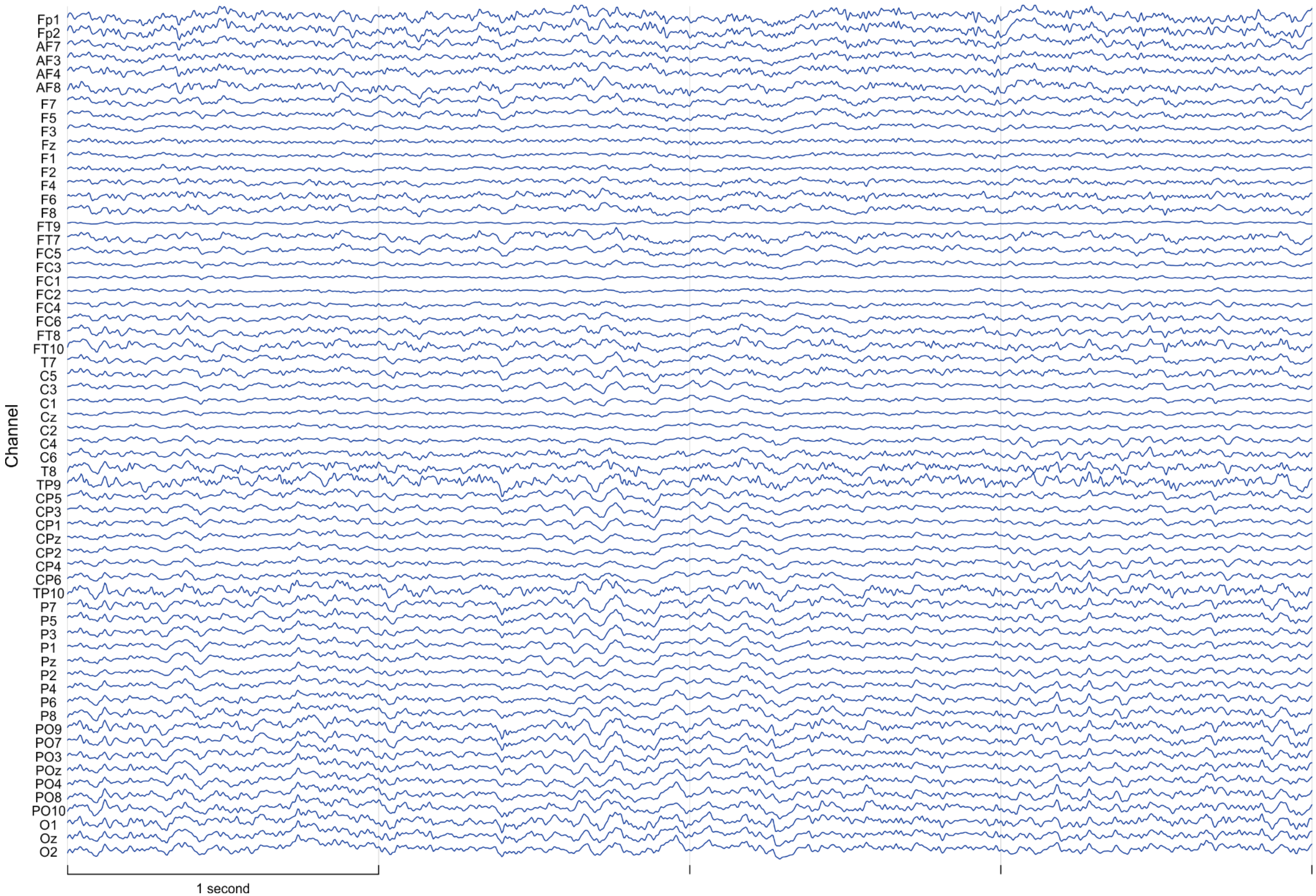
eye movements are a prominent source of artefacts in EEG recordings.

Eye movements

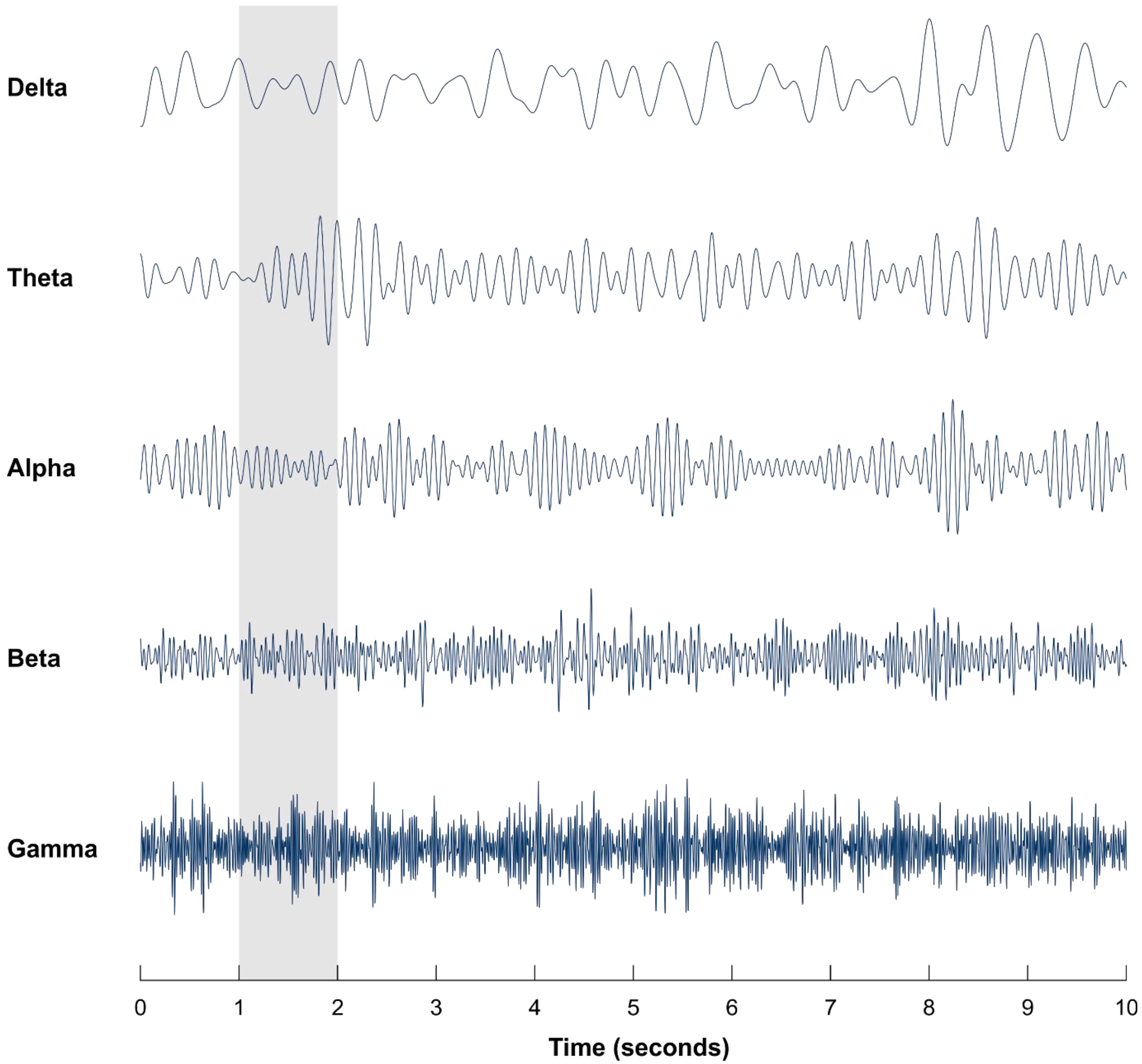




The electroencephalogram



Spontaneous EEG activity

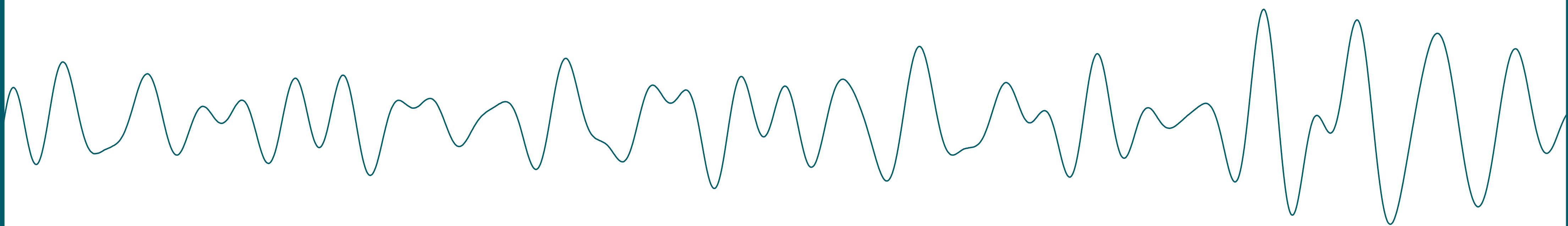


Delta rhythm (1-4 Hz)

- Associated with phases of deep sleep, which are therefore also known as “slow-wave sleep” phases

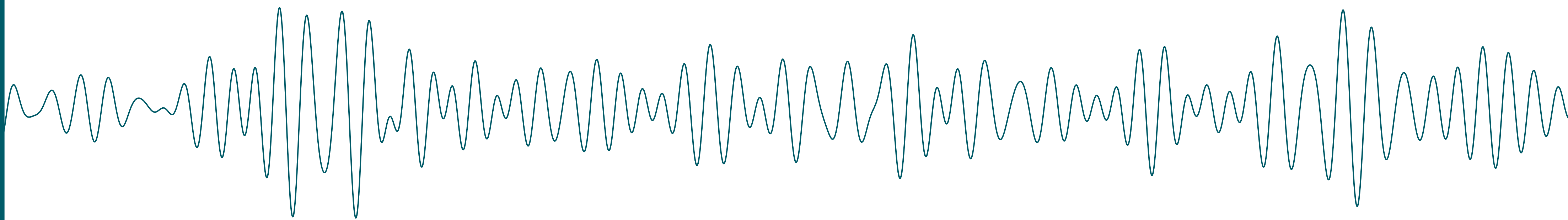
- Associated with (induces) the release of a number of hormones

- No known cognitive or affective correlates



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)

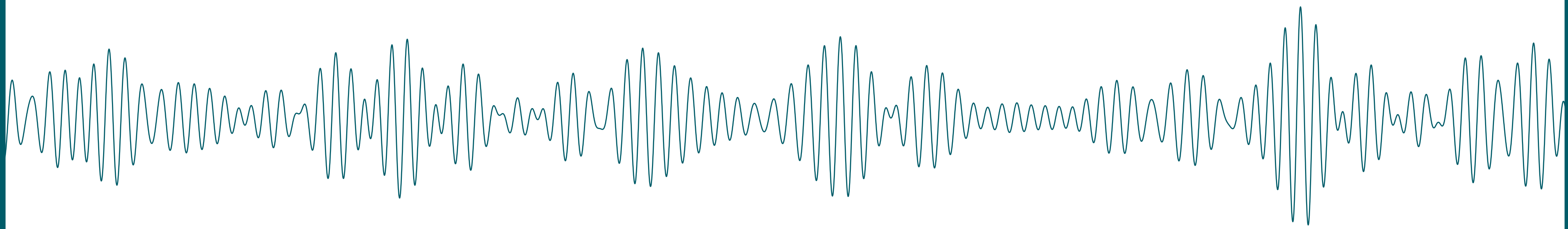


Alpha rhythm (8-12 Hz)

- Dominant regular frequency in human EEG (aside from bursts of delta activity)

- Most prominent during wakeful relaxation with closed eyes, primarily over occipital sites

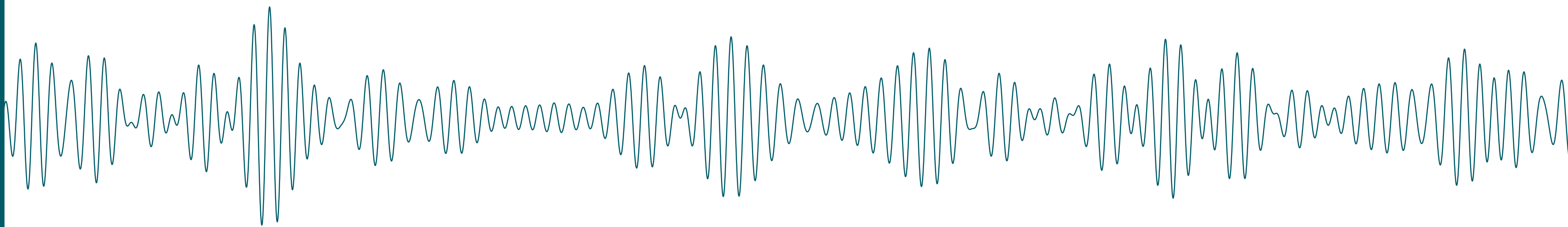
- Alpha desynchronization (reduced alpha activity) is associated with attention and cognitive work, especially in combination with simultaneous theta synchronization (increased activity)



Mu (sensorimotor) rhythm (8-13 Hz)

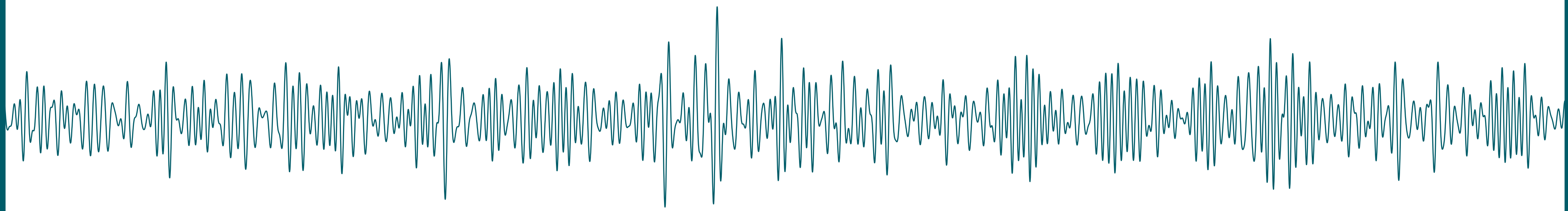
- Similar to alpha, but distinguished from the alpha rhythm by location: the mu rhythm is associated with the motor cortex

- 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

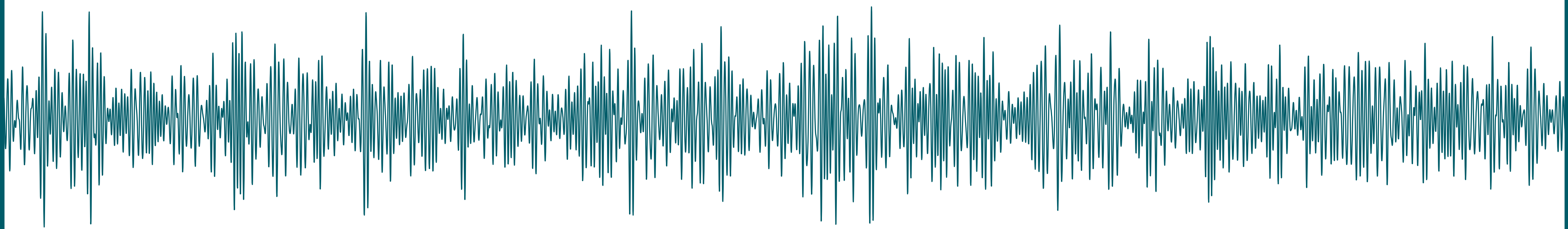


Gamma rhythm (30+ Hz)

- 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.

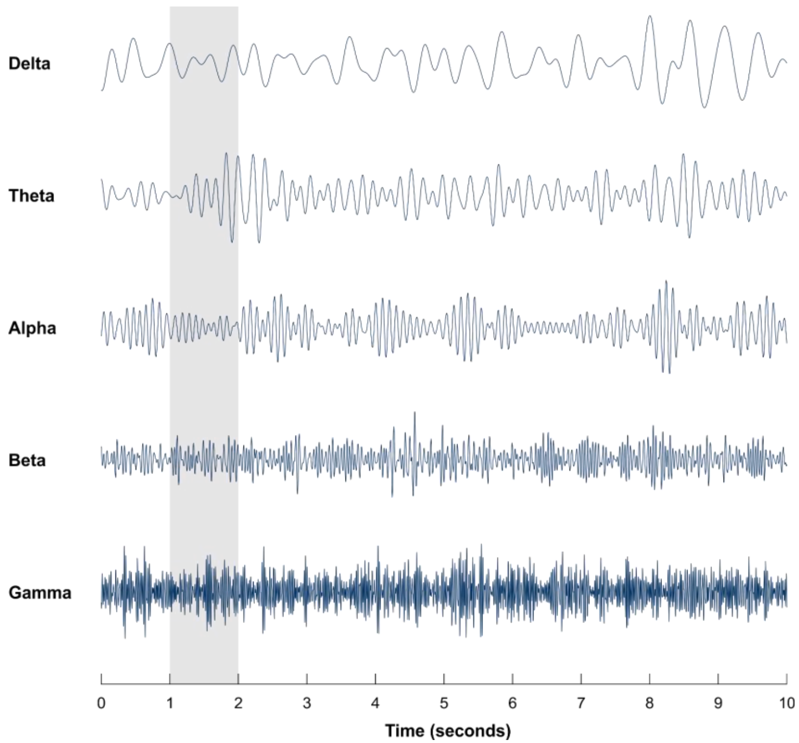
Peak frequencies vary across persons. Frequency band definitions are largely historical and vary from field to field, time to time, expert to expert.

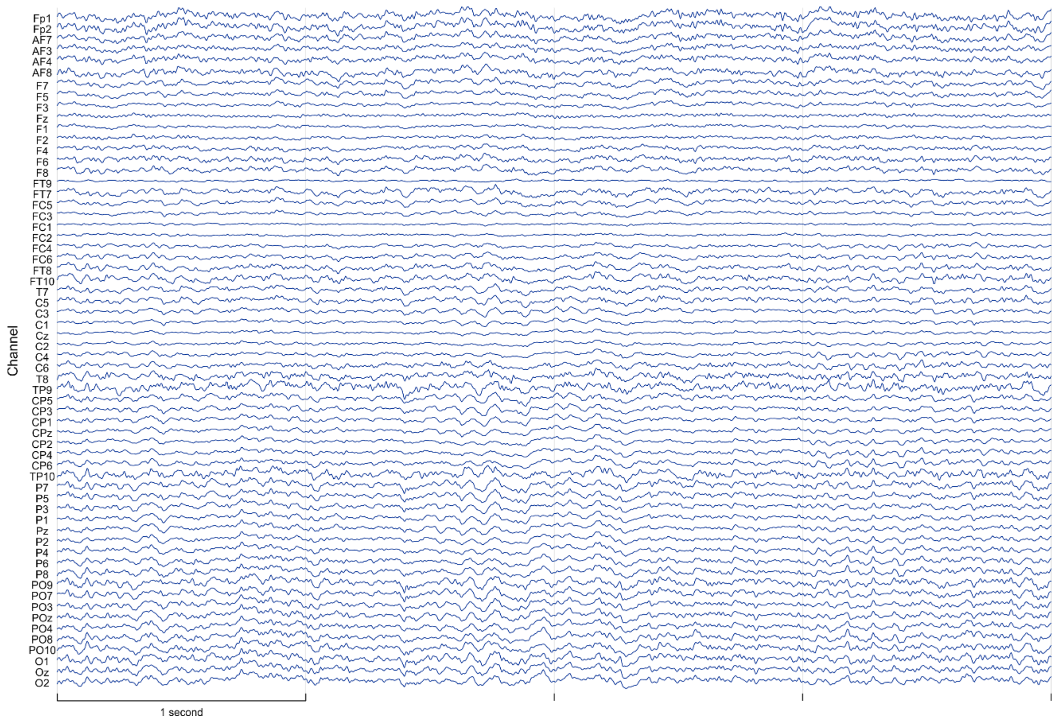
It is a gross simplification to simply equate activity of any frequency with any particular function.

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.)

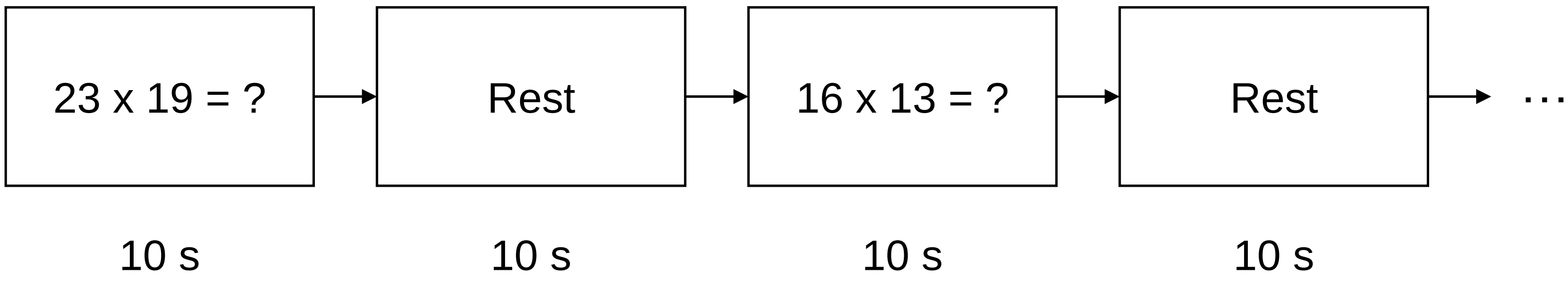
Example experiment: Workload

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.

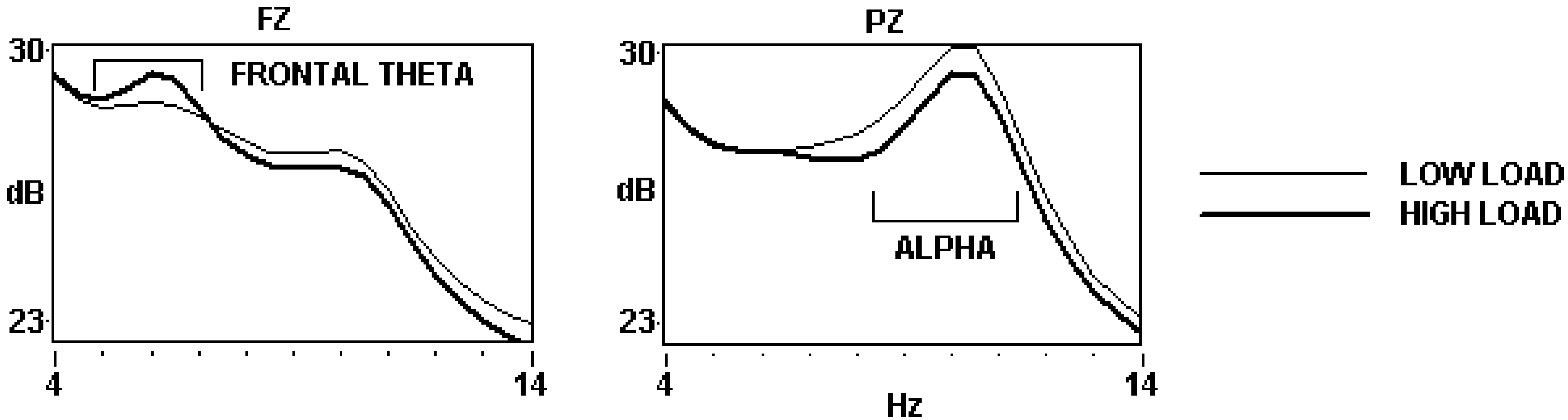


Figure: Gevins, A., & Smith, M. E. (2003). Neurophysiological measures of cognitive workload during human-computer interaction. *Theoretical Issues in Ergonomics Science, 4*(1–2), 113–131.