Chapter 9

Time and Spectral Analysis

EVOKED POTENTIALS

- Evoked potentials (EPs) are commonly used in clinical diagnosis, showcasing the application of signal averaging in physiology.
- The most frequently measured EPs are recorded with EEG electrode placement, representing neural activity in response to **auditory (AEP)**, **visual (VEP)**, or **somatosensory (SEP)** system stimulation.
- These examples capture activity associated with the primary perception process.
- Specialized evoked potentials exist, recording activity generated by more complex tasks performed by the nervous system.
- An example is **the oddball paradigm**, involving frequent baseline stimuli occasionally interrupted by a rare test stimulus.
- The oddball paradigm typically elicits a centrally located **positive wave at 300 ms** latency known as the **P300** in response to the rare stimulus.
- The P300 peak is generally interpreted as representing a neural response to stimulus novelty.

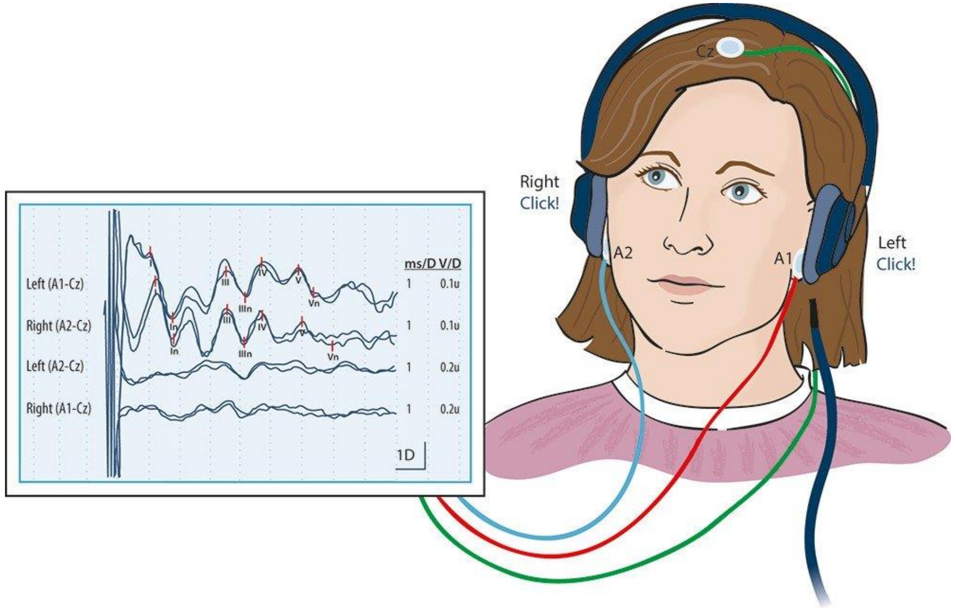
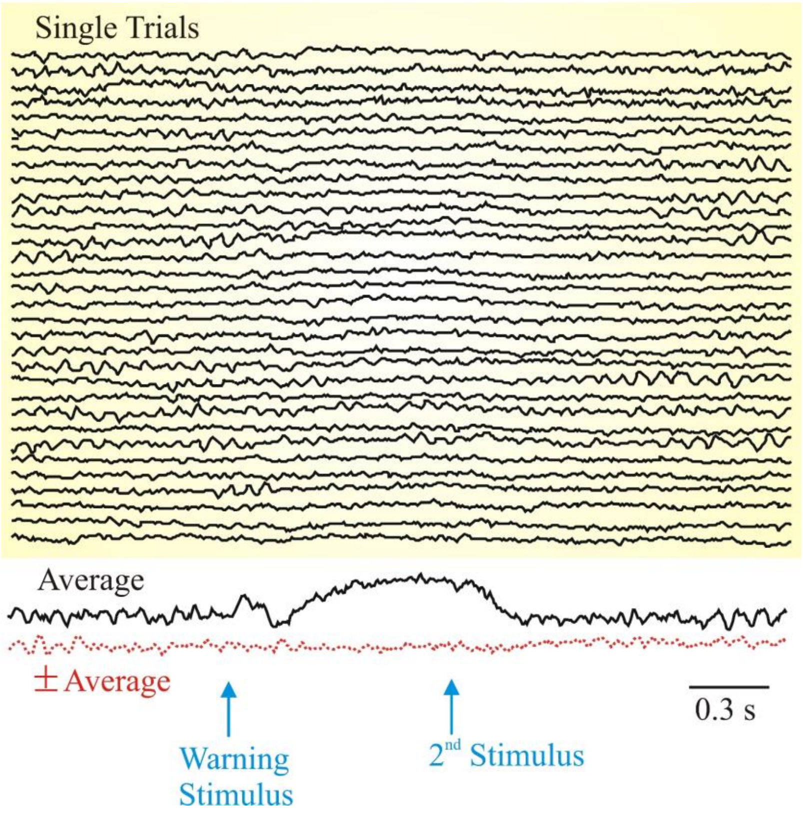


Figure 2, Sand, T., Mari Kvaloy, T. Wader and H. Hovdal. “Evoked potential tests in clinical diagnosis.” *Tidsskrift for den Norske laegeforening : tidsskrift for praktisk medicin, ny raekke* 133 9 (2013): 960-5

EVOKED POTENTIALS ...

- **The contingent negative variation (CNV)** paradigm is a more complex measurement involving a warning stimulus (usually a short tone burst) indicating an imminent second stimulus.
- In response to the second stimulus (usually a continuous tone or series of light flashes), the subject must turn it off with a button press.
- During the gap between the **warning and second stimulus**, a centrofrontal negative wave is observed in the CNV paradigm.
- The CNV signal is **weak relative to the ongoing EEG** and requires averaging to be obtained.
- Individual trials of the CNV paradigm show significant noise, but the average of only 32 trials clearly depicts the negative slope between stimuli.
- - The average serves as an estimate for the residual noise in the overall averaged result.



The contingent negative variation (CNV) measured from Cz (the apex of the scalp) is usually made visible in the average of individual trials in which a subject receives a warning stimulus that a second stimulation is imminent. The second stimulus must be turned off by a button press of the subject. The lower pair of traces shows the standard average revealing the underlying signal and the average as an estimate of the residual noise.

Figure 4.6 Signal processing for Neuroscientist, second edition by Wim van Drongelen

TIME DOMAIN ANALYSIS TECHNIQUES …

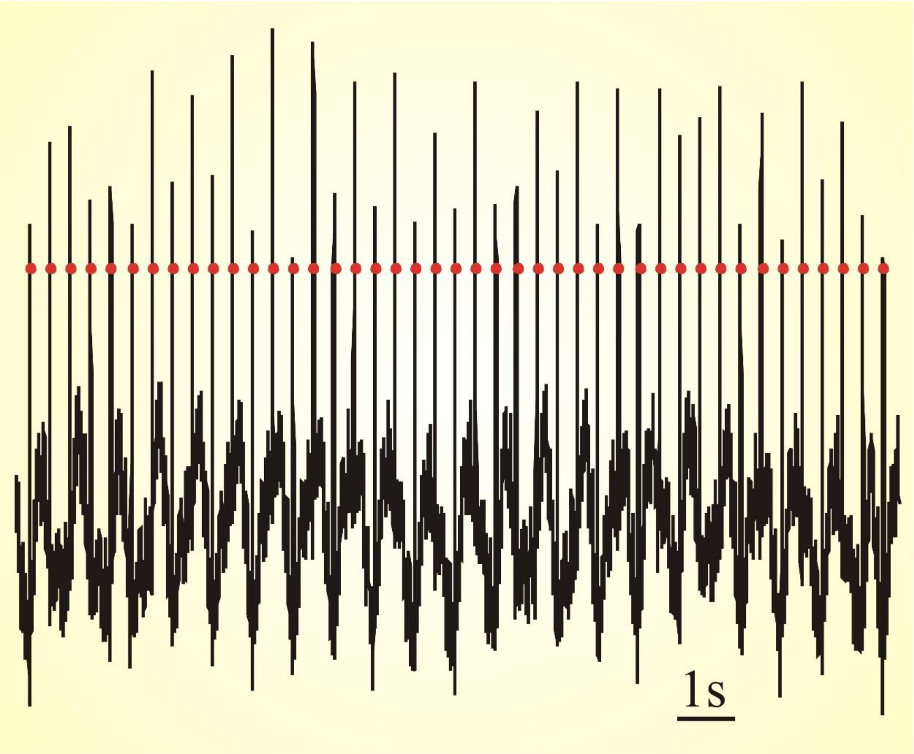
- Peak Detection

- Various methods are employed for peak detection in time series to locate extrema.

- Measurement of amplitudes between subsequent local maxima and minima allows determination of the amplitude distribution of the time series.

- Peak detection procedures are particularly useful in signals consisting of a series of impulses, helping calculate intervals between these events.

- This routine is commonly applied for detecting events in signals containing spikes, and in the electrocardiogram (ECG) for detecting QRS complexes.



An example of QRS complex detection in human neonates The general approach in these algorithms consists of two stages: first pretreat the signal in order to remove artifacts and then detect extreme values above a set threshold.

Figure 4.7 Signal processing for Neuroscientist, second edition by Wim van Drongelen

TIME DOMAIN ANALYSIS TECHNIQUES …

- Level and Window Detection

In some types of time series (such as in extracellular recordings of action potentials), one is interested in identifying epochs in which the signal is within a certain amplitude range. Analog- or digital-based window and level detectors are available to provide such data processing.

- Cross-Correlation

Cross-correlation can be used to quantify the relationship between different signals or between different parts of the same signal (termed “auto-correlation”).

- Template Matching

In some applications, signal features are extracted by correlating a known template with a time series. Wavelet and scaling signals can be considered special types of templates.

Brain Waves

- One of the main advantages of EEG over the other hemodynamics- or neurochemistry-based neuroimaging modalities, such as fMRI and PET, is its superior temporal resolution that makes it possible to investigate neuronal activities changing on the order of tens of milliseconds. Thanks to the **high temporal resolution** of EEG, a large amount of useful information can also be obtained **from frequency domain (or *spectral*) analysis**.
- EEG spectral analysis can also provide useful biomarkers to help diagnose and characterize various psychiatric diseases and neurological disorders. For example, reduced **frontal gamma-band** (30–50 Hz activity may **indicate declined cognitive function** and increased **midline beta-band (13–30 Hz) activity** may be an indicator of **rest less leg syndrome** .
- Spectral analysis can also be used to implement various types of brain–computer interfaces (BCIs) and neurofeedback systems .

Spontaneous brain activity

Brain waves are oscillating electrical voltages in the brain measuring just a few millionths of a volt. There are five widely recognized brain waves, and the main frequencies of human EEG waves are listed in Table below along with their characteristics.

Brain wave samples for different waveforms .Various regions of the brain do not emit the same brain wave frequency simultaneously.

An EEG signal between electrodes placed on the scalp consists of many waves with different characteristics. The large amount of data received from even one single EEG recording makes interpretation difficult. The brain wave patterns are unique for every individual.

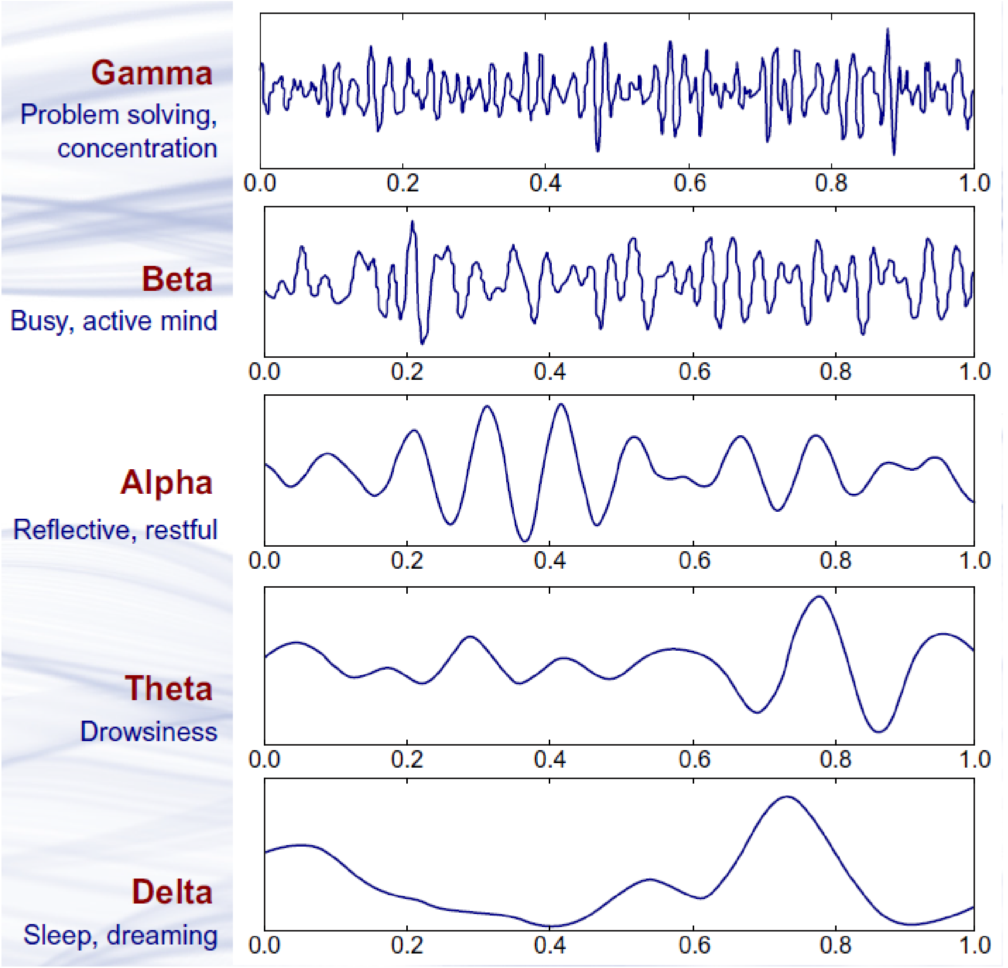


TABLE 2.1 Characteristics of the Five Basic Brain Waves

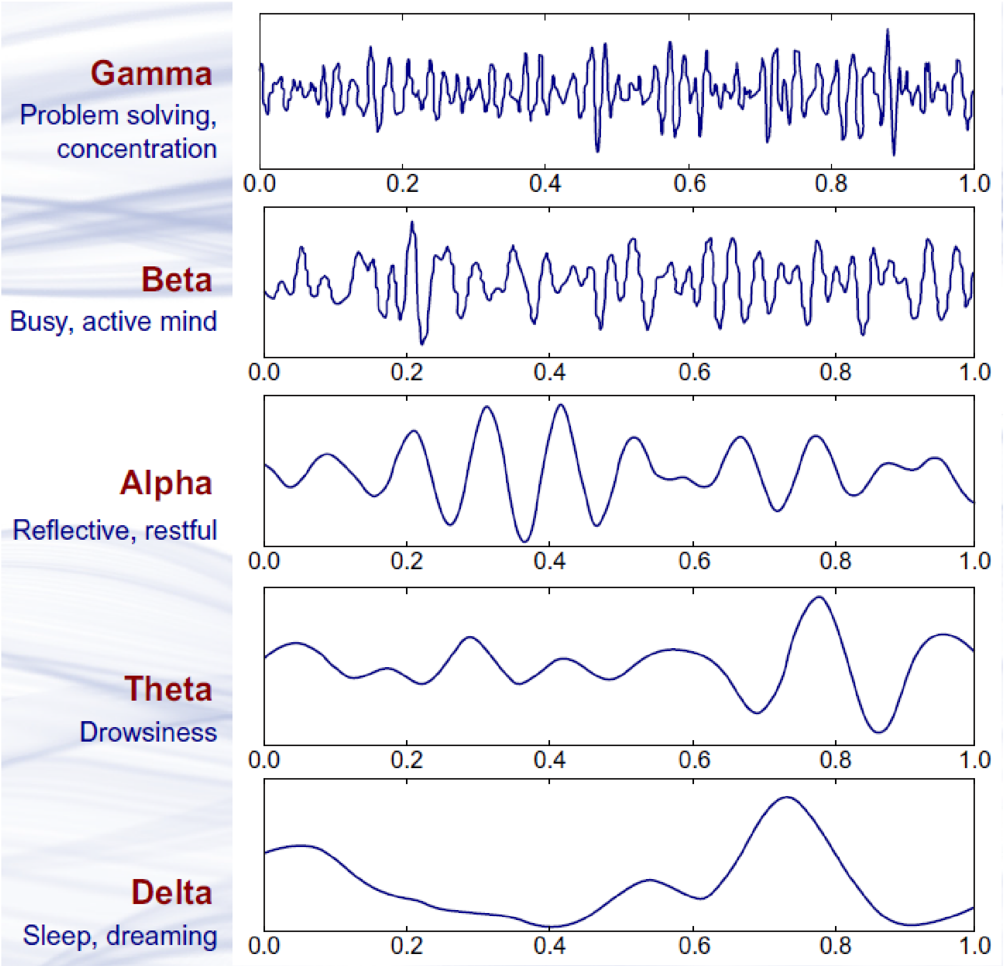
Frequency band	Frequency	Brain states
Gamma (γ)	>35 Hz	Concentration
Beta (β)	12–35 Hz	Anxiety dominant, active, external attention, relaxed
Alpha (α)	8–12 Hz	Very relaxed, passive attention
Theta (θ)	4–8 Hz	Deeply relaxed, inward focused
Delta (δ)	0.5–4 Hz	Sleep

Figure 2.1, and Table 2.1,Priyanka A. Abhang and et al, TECHNOLOGICAL BASICS OF EEG RECORDING AND OPERATION OF APPARATUS

Gamma (32 – 100 Hz)

Frequency: Associated state: Heightened perception, learning, problem-solving tasks.

Gamma brainwaves are the fastest measurable EEG brainwaves and have been equated to **'heightened perception'**, or a **'peak mental state'** when there is simultaneous processing of information from different parts of the brain. Gamma brainwaves have been observed to be much stronger and more regularly observed in very **long-term meditators** including **Buddhist Monks**.



Betta (13-32 Hz)

State: Alert, normal alert consciousness, active thinking

For example:

Active conversation

Making decisions

Solving a problem

Focusing on a task

Learning a new concept

Alpha (8-13 Hz)

State: Physically and mentally relaxed

Alpha brainwaves are some of the most easily observed and were the first to be discovered. They become detectable when the eyes are closed and the mind is relaxed. They can also often be found during activities such as:

- Yoga
- Just before falling asleep
- Being creative and artistic

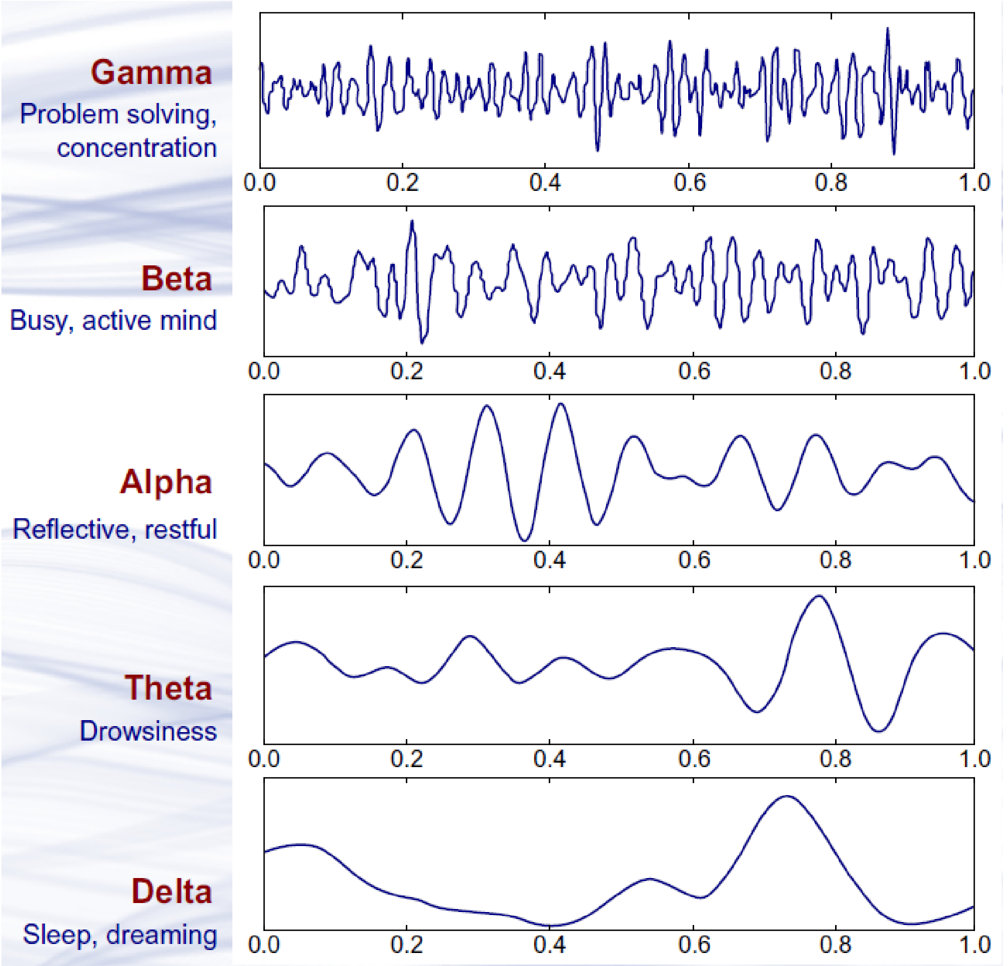
Theta (4-8 Hz)

State: Creativity, insight, dreams, reduced consciousness

previous studies have shown that theta waves indicate **deep relaxation** and occur more frequently in **highly experienced meditation practitioners**. The source is probably **frontal parts** of the brain, which are associated with monitoring of other mental processes."

Most frequently, theta brainwaves are strongly detectable when we're dreaming in our sleep (think, the movie *Inception*), but they can also be seen during :

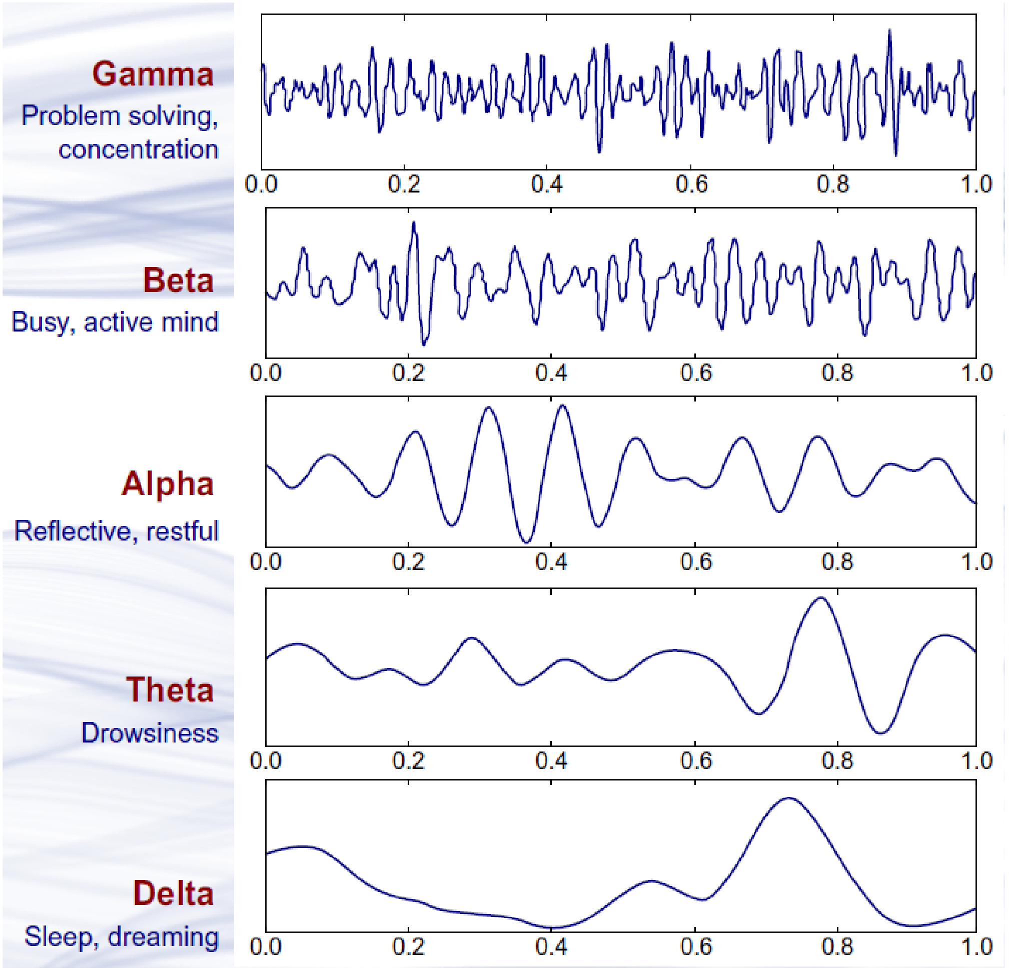
- Deep meditation
- Daydreaming
- When we're doing a task that is so automatic that the mind can disengage from it e.g. brushing teeth, showering.
- Research has also shown a positive association of theta waves with memory, creativity, and psychological well-being.



Delta (0.5 – 4Hz)

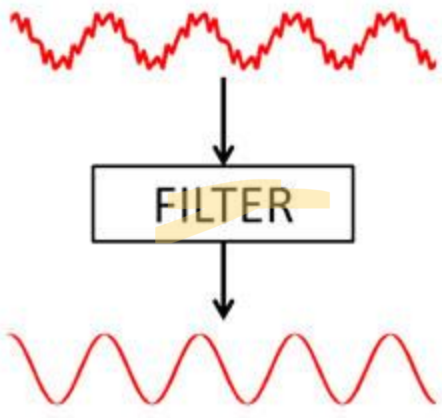
State: Sleep, dreaming

These are the slowest brainwaves and are strongest when we are in a dreamless, restorative sleep. This is also the state where healing and rejuvenation are stimulated, which is why it's so crucial to get enough sleep each night.

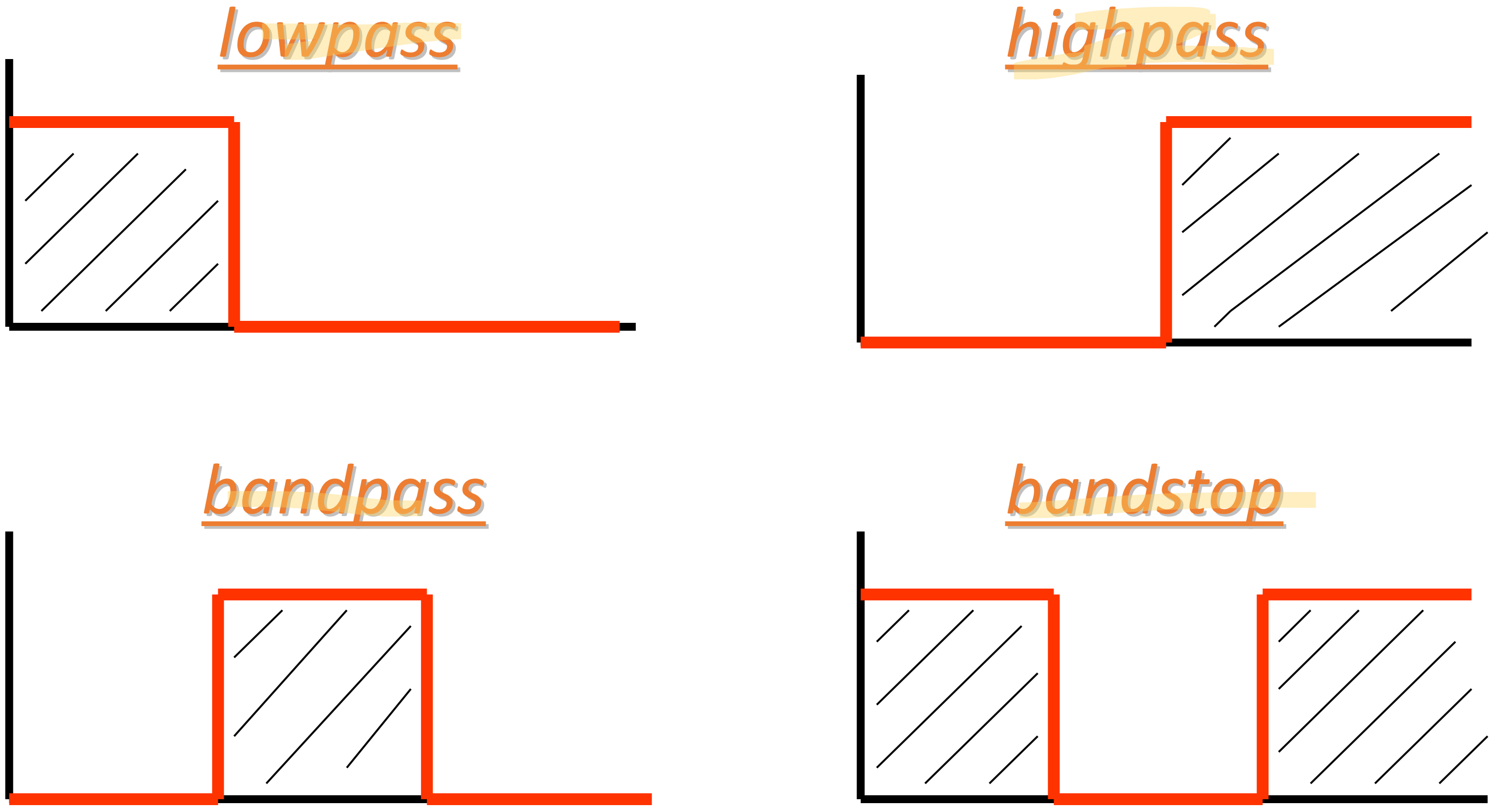


FREQUENCY DOMAIN ANALYSIS: Digital Filtering

- Filtering is the process of removing or separating the unwanted part of a mixture. In signal processing, filtering is specifically used to remove or extract part of a signal.



FREQUENCY DOMAIN ANALYSIS:
Digital Filtering (ideal)



FREQUENCY DOMAIN ANALYSIS:
Digital Filtering (Realistic)