**Univ of Missouri - Psych World – Decription of Brain Waves**

[**Delta Waves**](http://mentalhealthdaily.com/2014/04/14/delta-brain-waves-0-hz-to-4-hz/)

These are the slowest recorded brain waves in human beings. They are found most often in infants as well as young children. As we age, we tend to produce less delta even during deep sleep. They are associated with the deepest levels of relaxation and restorative, healing sleep. They have also been found to be involved in unconscious bodily functions such as regulating heart beat and digestion. Adequate production of delta waves helps us feel completely rejuvenated after we wake up from a good night’s sleep. If there is abnormal delta activity, an individual may experience learning disabilities or have difficulties maintaining conscious awareness (such as in cases of brain injuries).

* **Frequency range**: 0 Hz to 4 Hz (Slowest)
* **Too much**: Brain injuries, learning problems, inability to think, severe ADHD
* **Too little**: Inability to rejuvenate body, inability to revitalize the brain, poor sleep
* **Optimal**: Immune system, natural healing, restorative / deep sleep
* **Increase delta waves**: Depressants, sleep

[**Theta Waves**](http://mentalhealthdaily.com/2014/04/12/theta-brain-waves-4-hz-to-8-hz/)

This particular frequency range is involved in daydreaming and sleep. Theta waves are connected to us experiencing and feeling deep and raw emotions. Too much theta activity may make people prone to bouts of depression and may make them “highly suggestible” based on the fact that they are in a deeply relaxed, semi-hypnotic state. Theta has its benefits of helping improve our intuition, creativity, and makes us feel more natural. It is also involved in restorative sleep. As long as theta isn’t produced in excess during our waking hours, it is a very helpful brain wave range.

* **Frequency range**: 4 Hz to 8 Hz (Slow)
* **Too much**: ADHD, depression, hyperactivity, impulsivity, inattentiveness
* **Too little**: Anxiety, poor emotional awareness, stress
* **Optimal**: Creativity, emotional connection, intuition, relaxation
* **Increase theta waves**: Depressants

[**Alpha Waves**](http://mentalhealthdaily.com/2014/04/11/alpha-brain-waves-8-hz-to-12-hz/)

This frequency range bridges the gap between our conscious thinking and subconscious mind. In other words, alpha is the frequency range between beta and theta. It helps us calm down when necessary and promotes feelings of deep relaxation. If we become stressed, a phenomenon called “alpha blocking” may occur which involves excessive beta activity and very little alpha. Essentially the beta waves “block” out the production of alpha because we become too aroused.

* **Frequency range**: 8 Hz to 12 Hz (Moderate)
* **Too much**: Daydreaming, inability to focus, too relaxed
* **Too little**: Anxiety, high stress, insomnia, OCD
* **Optimal**: Relaxation
* **Increase alpha waves**: Alcohol, marijuana, relaxants, some antidepressants

[**Beta Waves**](http://mentalhealthdaily.com/2014/04/10/beta-brain-waves-12-hz-to-40-hz/)

These are known as high frequency low amplitude brain waves that are commonly observed while we are awake. They are involved in conscious thought, logical thinking, and tend to have a stimulating affect. Having the right amount of beta waves allows us to focus and complete school or work-based tasks easily. Having too much beta may lead to us experiencing excessive stress and/or anxiety. The higher beta frequencies are associated with high levels of arousal. When you drink caffeine or have another stimulant, your beta activity will naturally increase. Think of these as being very fast brain waves that most people exhibit throughout the day in order to complete conscious tasks such as: critical thinking, writing, reading, and socialization.

* **Frequency range**: 12 Hz to 40 Hz (High)
* **Too much**: Adrenaline, anxiety, high arousal, inability to relax, stress
* **Too little**: ADHD, daydreaming, depression, poor cognition
* **Optimal**: Conscious focus, memory, problem solving
* **Increase beta waves**: Coffee, energy drinks, various stimulants

[**Gamma Waves**](http://mentalhealthdaily.com/2014/03/12/gamma-brain-waves-40-hz-to-100-hz/)

These are involved in higher processing tasks as well as cognitive functioning. Gamma waves are important for learning, memory and information processing. It is thought that the 40 Hz gamma wave is important for the binding of our senses in regards to perception and are involved in learning new material. It has been found that individuals who are mentally challenged and have learning disabilities tend to have lower gamma activity than average.

* **Frequency range**: 40 Hz to 100 Hz (Highest)
* **Too much**: Anxiety, high arousal, stress
* **Too little**: ADHD, depression, learning disabilities
* **Optimal**: Binding senses, cognition, information processing, learning, perception, REM sleep
* **Increase gamma waves**: Meditation

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### Brain waves (Wikipedia)

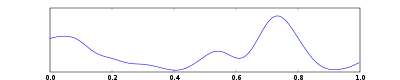
* [Delta wave](https://en.wikipedia.org/wiki/Delta_wave) – (0.1 – 3 Hz)
* [Theta wave](https://en.wikipedia.org/wiki/Theta_wave) – (4 – 7 Hz)
* Alpha wave – (8 – 15 Hz)
* [Mu wave](https://en.wikipedia.org/wiki/Mu_wave) – (7.5 – 12.5 Hz)
* [SMR wave](https://en.wikipedia.org/wiki/Sensorimotor_rhythm) – (12.5 – 15.5 Hz)
* [Beta wave](https://en.wikipedia.org/wiki/Beta_wave) – (16 – 31 Hz)
* [Gamma wave](https://en.wikipedia.org/wiki/Gamma_wave) – (32 – 100 Hz)

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# Delta wave

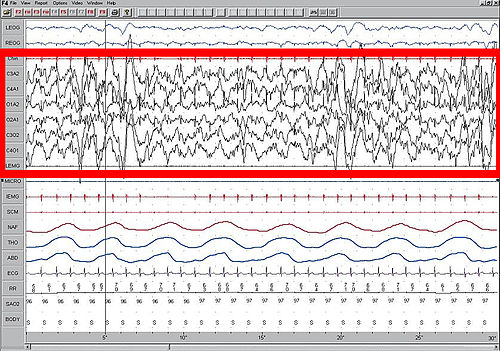
From Wikipedia, the free encyclopedia

For the medical syndrome, see [Wolff-Parkinson-White syndrome](https://en.wikipedia.org/wiki/Wolff-Parkinson-White_syndrome).

[](https://en.wikipedia.org/wiki/File:Eeg_delta.svg)

Delta waves, an EEG (electroencephalograph) one second sample

A **delta wave** is a high [amplitude](https://en.wikipedia.org/wiki/Amplitude) [brain wave](https://en.wikipedia.org/wiki/Neural_oscillation) with a frequency of oscillation between 0–4 [hertz](https://en.wikipedia.org/wiki/Hertz). Delta waves, like other brain waves, are recorded with an [electroencephalogram](https://en.wikipedia.org/wiki/Electroencephalography)[[1]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-isbn0-550-14110-3-1) (EEG) and are usually associated with the deep stage 3 of [NREM](https://en.wikipedia.org/wiki/NREM) sleep, also known as [slow-wave sleep](https://en.wikipedia.org/wiki/Slow-wave_sleep) (SWS), and aid in characterizing the depth of sleep.

[](https://en.wikipedia.org/wiki/File:Sleep_EEG_Stage_4.jpg)

This is a screen shot of a patient during Slow Wave Sleep (stage 3). The high amplitude EEG is highlighted in red. This screen shot represents a 30 second epoch (30 seconds of data).

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## Background and history

"Delta waves" were first described in the early 1900s by [W. Grey Walter](https://en.wikipedia.org/wiki/W._Grey_Walter), who improved upon Dr. [Hans Berger](https://en.wikipedia.org/wiki/Hans_Berger)'s [electroencephalograph](https://en.wikipedia.org/wiki/Electroencephalograph) machine (EEG) to detect alpha and delta waves. Delta waves can be quantified using [Quantitative electroencephalography (qEEG)](https://en.wikipedia.org/wiki/Quantitative_electroencephalography) using freely available toolboxes, such as, [EEGLAB](https://en.wikipedia.org/wiki/EEGLAB) or the [Neurophysiological Biomarker Toolbox (NBT)](http://www.nbtwiki.net).

## Classification and features

Delta waves, like all brain waves, are detected by [electroencephalography](https://en.wikipedia.org/wiki/Electroencephalography) (EEG). Delta waves were originally defined as having a frequency between 1-4 [Hz](https://en.wikipedia.org/wiki/Hertz), although more recent classifications put the boundaries at between 0.5 and 2 Hz. They are the slowest, but highest amplitude brainwaves. Delta waves begin to appear in stage 3 sleep, but by stage 4 nearly all spectral activity is dominated by delta waves. Stage 3 sleep is defined as having less than 50% delta wave activity, while stage 4 sleep has more than 50% delta wave activity. These stages have recently been combined and are now collectively referred to as [stage](https://en.wikipedia.org/wiki/Sleep#NREM_sleep) N3 slow-wave sleep.[[2]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-2) During N3 SWS, delta waves account for 20% or more of the EEG record during this stage.[[3]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-3) Delta waves occur in all mammals, and potentially all animals as well.

Delta waves are often associated with another EEG phenomenon, the [K-complex](https://en.wikipedia.org/wiki/K-complex). K-Complexes have been shown to immediately precede delta waves in slow wave sleep.[[4]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-4)

## Neurophysiology

### Sex differences

Women have been shown to have more delta wave activity, and this is true across most mammal species. This discrepancy does not become apparent until early adulthood (in the 30's or 40's, in humans), with men showing greater age-related reductions in delta wave activity than women.[[5]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-5) It has been suggested[*[citation needed](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed" \o "Wikipedia:Citation needed)*] that this discrepancy may be due to larger skull size in males, but this theory has been refuted[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] by intracranial data from female cats, which still show more delta activity.

### Brain localization and biochemistry

Delta waves can arise either in the thalamus or in the cortex. When associated with the thalamus, they are thought to arise in coordination with the [reticular formation](https://en.wikipedia.org/wiki/Reticular_formation).[[6]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-isbn034056136x-6)[[7]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-7) In the cortex, the [suprachiasmatic nuclei](https://en.wikipedia.org/wiki/Suprachiasmatic_nuclei) have been shown to regulate delta waves, as lesions to this area have been shown to cause disruptions in delta wave activity. In addition, delta waves show a lateralization, with right hemisphere dominance during sleep.[[8]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-8) Delta waves have been shown to be mediated in part by [T-type calcium channels](https://en.wikipedia.org/wiki/T-type_calcium_channel).[[9]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-9) During delta wave sleep, neurons are globally inhibited by [gamma-aminobutyric acid](https://en.wikipedia.org/wiki/Gamma-aminobutyric_acid) (GABA).[[10]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-Hobson.2C_J._2002-10)

Delta activity stimulates the release of several hormones, including growth hormone releasing hormone [GHRH](https://en.wikipedia.org/wiki/GHRH) and [prolactin](https://en.wikipedia.org/wiki/Prolactin) (PRL). GHRH is released from the [hypothalamus](https://en.wikipedia.org/wiki/Hypothalamus), which in turn stimulates release of [growth hormone](https://en.wikipedia.org/wiki/Growth_hormone) (GH) from the [pituitary](https://en.wikipedia.org/wiki/Pituitary). The secretion of (PRL), which is closely related to (GH), is also regulated by the pituitary. The release of [thyroid stimulating hormone](https://en.wikipedia.org/wiki/Thyroid_stimulating_hormone) (TSH), is decreased in response to delta-wave signaling.[[11]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-11)

## Development

Infants have been shown to spend a great deal of time in [slow-wave sleep](https://en.wikipedia.org/wiki/Slow-wave_sleep), and thus have more delta wave activity. In fact, delta-waves are the predominant wave forms of infants. Analysis of the [waking](https://en.wikipedia.org/wiki/Wakefulness) EEG of a [newborn](https://en.wikipedia.org/wiki/Newborn) infant indicates that delta wave activity is predominant in that age, and still appears in a waking EEG of five-year-olds.[[12]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-isbn0-632-05361-5-12) Delta wave activity during slow-wave sleep declines during adolescence, with a drop of around 25% reported between the ages of 11 and 14 years.[[13]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-13) Delta waves have been shown to decrease across the lifespan, with most of the decline seen in the mid-forties. By the age of about 75, stage four sleep and delta waves may be entirely absent.[[14]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-14) In addition to a decrease in the incidence of delta waves during slow-wave sleep in the elderly, the incidence of temporal delta wave activity is commonly seen in older adults, and incidences also increase with age.[[15]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-15)

## Disruptions and disorders

Regional delta wave activity not associated with NREM sleep was first described by [W. Grey Walter](https://en.wikipedia.org/wiki/W._Grey_Walter), who studied [cerebral hemisphere](https://en.wikipedia.org/wiki/Cerebral_hemisphere) tumors. Disruptions in delta wave activity and slow wave sleep are seen in a wide array of disorders. In some cases there may be increases or decreases in delta wave activity, while others may manifest as disruptions in delta wave activity, such as alpha waves presenting in the EEG spectrum. Delta wave disruptions may present as a result of physiological damage, changes in nutrient metabolism, chemical alteration, or may also be idiopathic. Disruptions in delta activity is seen in adults during states of [intoxication](https://en.wikipedia.org/wiki/Substance_intoxication) or [delirium](https://en.wikipedia.org/wiki/Delirium) and in those diagnosed with various neurological disorders such as [dementia](https://en.wikipedia.org/wiki/Dementia) or [schizophrenia](https://en.wikipedia.org/wiki/Schizophrenia).[[16]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-isbn1-58562-239-7-16)

### Temporal Low-voltage Irregular Delta Wave

Temporal low-voltage irregular delta wave activity has been commonly detected in patients with [ischemic](https://en.wikipedia.org/wiki/Ischemic) brain diseases, particularly in association with small ischemic lesions and is seen to be indicative of early-stage [cerebrovascular](https://en.wikipedia.org/wiki/Cerebrovascular) damage.[[17]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-17)

### Parasomnias

[Parasomnias](https://en.wikipedia.org/wiki/Parasomnias), a category of [sleep disorders](https://en.wikipedia.org/wiki/Sleep_disorders), are often associated with disruptions in slow wave sleep. [Sleep walking](https://en.wikipedia.org/wiki/Sleep_walking) and sleep talking most often occur during periods of high delta wave activity. Sleep walkers have also been shown to have more hypersynchronous delta activity (HSD) compared to total time spent in stages 2, 3, and 4 sleep relative to healthy controls. HSD refers to the presence of continuous, high-voltage (> 150 uV) delta waves seen in sleep EEGs.[[18]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-ReferenceA-18) Parasomnias which occur deep in NREM sleep also include [sleep terrors](https://en.wikipedia.org/wiki/Sleep_terrors) and confusional arousals.

### Sleep deprivation

Total sleep deprivation has been shown to increase delta wave activity during sleep recovery,[[19]](https://en.wikipedia.org/wiki/Delta_wave" \l "cite_note-19) and has also been shown to increase hypersynchronous delta activity.[[18]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-ReferenceA-18)

### Parkinson's disease

Sleep disturbances, as well as [dementia](https://en.wikipedia.org/wiki/Dementia), are common features of [Parkinson's disease](https://en.wikipedia.org/wiki/Parkinson%27s_disease), and patients with this disease show disrupted brain wave activity. The drug [Rotigotine](https://en.wikipedia.org/wiki/Rotigotine), developed for the treatment of Parkinson's disease, has been shown to increase delta power and slow-wave sleep. Delta-wave inducing peptide injected into the [substantia nigra](https://en.wikipedia.org/wiki/Substantia_nigra) of the rat model has been shown to increase Parkinsonian symptoms.[[20]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-20)

### Schizophrenia

People suffering schizophrenia have shown disrupted EEG patterns, and there is a close association of reduced delta waves during deep sleep and negative symptoms associated with [schizophrenia](https://en.wikipedia.org/wiki/Schizophrenia). During slow wave sleep (stages 3 and 4), schizophrenics have been shown to have reduced delta wave activity, although delta waves have also been shown to be increased during waking hours in more severe forms of schizophrenia.[[21]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-21) A recent study has shown that the right frontal and central delta wave dominance, seen in healthy individuals, is absent in patients with schizophrenia. In addition, the negative correlation between delta wave activity and age is also not observed in those with schizophrenia.[[22]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-22)

### Diabetes and insulin resistance

Disruptions in slow wave (delta) sleep have been shown to increase risk for development of Type II diabetes, potentially due to disruptions in the growth hormone secreted by the pituitary. In addition, hypoglycemia occurring during sleep may also disrupt delta-wave activity.[[23]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-23) Low-voltage irregular delta waves, have also been found in the left temporal lobe of diabetic patients, at a rate of 56% (compared to 14% in healthy controls).[[24]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-24)[[25]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-25)

### Fibromyalgia

Patients suffering from [fibromyalgia](https://en.wikipedia.org/wiki/Fibromyalgia) often report unrefreshing sleep. A study conducted in 1975 by Moldovsky *et al.* showed that the delta wave activity of these patients in stages 3 and 4 sleep were often interrupted by [alpha waves](https://en.wikipedia.org/wiki/Alpha_wave). They later showed that depriving the body of delta wave sleep activity also induced [musculoskeletal](https://en.wikipedia.org/wiki/Musculoskeletal) pain and [fatigue](https://en.wikipedia.org/wiki/Fatigue_%28medical%29).[[26]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-26)

### Alcoholism

Alcohol has been shown to decrease slow wave sleep and delta power, while increasing stage 1 and REM incidence in both men and women. In long-term alcohol abuse, the influences of alcohol on sleep architecture and reductions in delta activity have been shown to persist even after long periods of abstinence.[[27]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-27)

### Temporal lobe epilepsy

Slow waves, including delta waves, are associated with seizure-like activity within the brain. [W. Grey Walter](https://en.wikipedia.org/wiki/W._Grey_Walter) was the first person to use delta waves from an [EEG](https://en.wikipedia.org/wiki/EEG) to locate [brain tumors](https://en.wikipedia.org/wiki/Brain_tumors) and lesions causing [temporal lobe epilepsy](https://en.wikipedia.org/wiki/Temporal_lobe_epilepsy).[[28]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-28) [Neurofeedback](https://en.wikipedia.org/wiki/Neurofeedback) has been suggested as a treatment for temporal lobe epilepsy, and theoretically acts to reduce inappropriate delta wave intrusion, although there has been limited clinical research in this area.[[29]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-29)

### Other disorders

Other disorders frequently associated with disrupted delta-wave activity include:

* [Narcolepsy](https://en.wikipedia.org/wiki/Narcolepsy)
* [Depression](https://en.wikipedia.org/wiki/Depression_%28clinical%29)
* [Anxiety](https://en.wikipedia.org/wiki/Anxiety)
* [Obsessive–compulsive disorder](https://en.wikipedia.org/wiki/Obsessive%E2%80%93compulsive_disorder)
* [Attention deficit hyperactivity disorder](https://en.wikipedia.org/wiki/Attention_deficit_hyperactivity_disorder) (ADHD) and its three subtypes.[[30]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-30)
* [Juvenile chronic arthritis](https://en.wikipedia.org/wiki/Juvenile_chronic_arthritis)[[31]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-31)

## Consciousness and dreaming

Initially, dreaming was thought to only occur in rapid eye movement sleep, though it is now known that dreaming may also occur during slow-wave sleep. Delta waves and delta wave activity are marked, in most people, by an apparently unconscious state, and the loss of physical awareness as well as the "iteration of information". Nevertheless, some people who practice a type of deep meditation called [Yoga Nidra](https://en.wikipedia.org/wiki/Yoga_Nidra) (*Sleep yoga*) can remain conscious while in delta-sleep.[[32]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-32)

Delta wave activity has also been purported to aid in the formation of declarative and explicit memory formation. [[10]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-Hobson.2C_J._2002-10)

## Cultural and religious role

In [Advaita Vedanta](https://en.wikipedia.org/wiki/Advaita_Vedanta), deep dreamless sleep is considered the highest state of consciousness. If one can stay aware or conscious while in deepest dreamless sleep, a deep meditative state (known as "jagrat sushupti") is said to be achievable. This notion of paradoxical [consciousness](https://en.wikipedia.org/wiki/Consciousness) may be linked to high cortical activity which happens during the delta-sleep. [[33]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-33)

## Pharmacology

While most drugs that affect sleep do so by stimulating sleep onset, or disrupting REM sleep, a number of chemicals and drugs have been shown to alter delta wave activity.

* [Delta sleep-inducing peptide](https://en.wikipedia.org/wiki/Delta_sleep-inducing_peptide), as the name suggests, induces delta wave EEG activity.
* Alcohol reduces SWS delta wave activity, thereby restricting the release of [growth hormone](https://en.wikipedia.org/wiki/Growth_hormone) (GH) by the pituitary.[[34]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-34)
* The muramyl peptide, muramyl dipeptide (MDP, N-acetylmuramyl-L-alanyl-D-isoglutamine) has been shown to increase delta wave activity during slow wave sleep.[[35]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-35)
* The drug [Gabapentin](https://en.wikipedia.org/wiki/Gabapentin), a drug used to control epileptic seizures, increases delta-wave activity and slow wave sleep in adults.[[36]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-36)
* While hypnotic drugs increase slow wave sleep, they do not increase delta wave activity, and instead increase spindle activity during slow wave sleep.[[37]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-D.27haenen.2C_H._A._H._2002-37)
* [Gamma-hydroxy butyrate](https://en.wikipedia.org/wiki/Gamma-Hydroxybutyric_acid) (GHB) increases delta slow-wave sleep as well as sleep-related growth hormone (GH).[[37]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-D.27haenen.2C_H._A._H._2002-37)

## Effects of diet

Diets very low in carbohydrates, such as a [ketogenic diet](https://en.wikipedia.org/wiki/Ketogenic_diet), have been shown to increase the amount of delta activity and slow wave sleep in healthy individuals.[[38]](https://en.wikipedia.org/wiki/Delta_wave#cite_note-38)

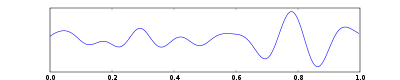
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# Theta rhythm

From Wikipedia, the free encyclopedia

  (Redirected from [Theta wave](https://en.wikipedia.org/w/index.php?title=Theta_wave&redirect=no))

"Thetawaves" redirects here. "Thetawaves" is also a song on [Steal This Album!](https://en.wikipedia.org/wiki/Steal_This_Album%21).

[](https://en.wikipedia.org/wiki/File:Eeg_theta.svg)

Example of an EEG theta wave

The **theta rhythm** is an [oscillatory](https://en.wikipedia.org/wiki/Neural_oscillation) pattern in [electroencephalography](https://en.wikipedia.org/wiki/Electroencephalography)(EEG) signals recorded either from inside the brain or from electrodes glued to the scalp. Two types of theta rhythm have been described. The *"hippocampal theta rhythm"* is a strong oscillation that can be observed in the [hippocampus](https://en.wikipedia.org/wiki/Hippocampus) and other brain structures in numerous species of [mammals](https://en.wikipedia.org/wiki/Mammal) including rodents, rabbits, dogs, cats, bats, and marsupials. *"Cortical theta rhythms"* are low-frequency components of scalp EEG, usually recorded from humans. Theta rhythms can be quantified using [Quantitative electroencephalography (qEEG)](https://en.wikipedia.org/wiki/Quantitative_electroencephalography) using freely available toolboxes, such as, [EEGLAB](https://en.wikipedia.org/wiki/EEGLAB) or the Neurophysiological Biomarker Toolbox (NBT).

In rats, the most frequently studied species, theta rhythmicity is easily observed in the hippocampus, but can also be detected in numerous other cortical and subcortical brain structures. Hippocampal theta, with a frequency range of 6–10 Hz, appears when a rat is engaged in active motor behavior such as walking or exploratory sniffing, and also during [REM sleep](https://en.wikipedia.org/wiki/Rapid_eye_movement_sleep). Theta waves with a lower frequency range, usually around 6–7 Hz, are sometimes observed when a rat is motionless but alert. When a rat is eating, grooming, or sleeping, the hippocampal EEG usually shows a non-rhythmic pattern known as [Large irregular activity](https://en.wikipedia.org/wiki/Large_irregular_activity) or *LIA*. The hippocampal theta rhythm depends critically on projections from the [medial septal area](https://en.wikipedia.org/wiki/Septal_nuclei), which in turn receives input from the [hypothalamus](https://en.wikipedia.org/wiki/Hypothalamus) and several brainstem areas. Hippocampal theta rhythms in other species differ in some respects from those in rats. In cats and rabbits, the frequency range is lower (around 4–6 Hz), and theta is less strongly associated with movement than in rats. In bats, theta appears in short bursts associated with echolocation. In humans and other primates, hippocampal theta is difficult to observe at all.

The function of the hippocampal theta rhythm is not clearly understood. Green and Arduini, in the first major study of this phenomenon, noted that hippocampal theta usually occurs together with desynchronized EEG in the [neocortex](https://en.wikipedia.org/wiki/Neocortex), and proposed that it is related to arousal. Vanderwolf and his colleagues, noting the strong relationship between theta and motor behavior, have argued that it is related to sensorimotor processing. Another school, led by John O'Keefe, have suggested that theta is part of the mechanism animals use to keep track of their location within the environment. The most popular theories, however, link the theta rhythm to mechanisms of learning and memory ([Hasselmo, 2005](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refHasselmo2005b)).

Cortical theta rhythms observed in human scalp EEG are a different phenomenon, with no clear relationship to the hippocampus. In human EEG studies, the term *theta* refers to frequency components in the 4–7 Hz range, regardless of their source. Cortical theta is observed frequently in young children. In older children and adults, it tends to appear during meditative, drowsy, or sleeping states, but not during the deepest stages of sleep. Several types of brain pathology can give rise to abnormally strong or persistent cortical theta waves.

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## History

Although there were a few earlier hints, the first clear description of regular slow oscillations in the hippocampal EEG came from a paper written in German by Jung and Kornmüller ([1938](https://en.wikipedia.org/wiki/Theta_rhythm#refJung1938)) They were not able to follow up on these initial observations, and it was not until 1954 that further information became available, in a very thorough study by John D. Green and Arnaldo Arduini that mapped out the basic properties of hippocampal oscillations in cats, rabbits, and monkeys ([Green and Arduini, 1954](https://en.wikipedia.org/wiki/Theta_rhythm#refGreen1954)). Their findings provoked widespread interest, in part because they related hippocampal activity to arousal, which was at that time the hottest topic in neuroscience. Green and Arduini described an inverse relationship between hippocampal and cortical activity patterns, with hippocampal rhythmicity occurring alongside desynchronized activity in the cortex, whereas an irregular hippocampal activity pattern was correlated with the appearance of large slow waves in the cortical EEG.

Over the following decade came an outpouring of experiments examining the pharmacology and physiology of theta. By 1965, Charles Stumpf was able to write a lengthy review of "Drug action on the electrical activity of the hippocampus" citing hundreds of publications ([Stumpf, 1965](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refStumpf1965)), and in 1964 John Green, who served as the leader of the field during this period, was able to write an extensive and detailed review of hippocampal electrophysiology ([Green, 1964](https://en.wikipedia.org/wiki/Theta_rhythm#refGreen1964)). A major contribution came from a group of investigators working in Vienna, including Stumpf and Wolfgang Petsche, who established the critical role of the medial septum in controlling hippocampal electrical activity, and worked out some of the pathways by which it exerts its influence.

## Terminology

Because of a historical accident, the term "theta rhythm" is used to refer to two different phenomena, *"hippocampal theta"* and *"human cortical theta"*. Both of these are oscillatory EEG patterns, but they may have little in common beyond the name "theta"[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)].

In the oldest [EEG](https://en.wikipedia.org/wiki/EEG) literature dating back to the 1920s, Greek letters such as alpha, beta, theta, and gamma were used to classify EEG waves falling into specific frequency ranges, with "theta" generally meaning a range of about 4–7 cycles per second (Hz). In the 1930s–1950s, a very strong rhythmic oscillation pattern was discovered in the [hippocampus](https://en.wikipedia.org/wiki/Hippocampus) of cats and rabbits ([Green & Arduini, 1954](https://en.wikipedia.org/wiki/Theta_rhythm#refGreen1954)). In these species, the hippocampal oscillations fell mostly into the 4–6 Hz frequency range, so they were referred to as "theta" oscillations. Later, hippocampal oscillations of the same type were observed in rats; however, the frequency of rat hippocampal EEG oscillations averaged about 8 Hz and rarely fell below 6 Hz. Thus the rat hippocampal EEG oscillation should not, strictly speaking, have been called a "theta rhythm". However the term "theta" had already become so strongly associated with hippocampal oscillations that it continued to be used even for rats. Over the years this association has come to be stronger than the original association with a specific frequency range, but the original meaning also persists.

Thus, "theta" can mean either of two things:

1. A specific type of regular oscillation seen in the hippocampus and several other brain regions connected to it.
2. EEG oscillations in the 4–7 Hz frequency range, regardless of where in the brain they occur or what their functional significance is.

The first meaning is usually intended in literature that deals with rats or mice, while the second meaning is usually intended in studies of human EEG recorded using electrodes glued to the scalp. In general, it is not safe to assume that observations of "theta" in the human EEG have any relationship to the "hippocampal theta rhythm". Scalp EEG is generated almost entirely by the [cerebral cortex](https://en.wikipedia.org/wiki/Cerebral_cortex), and even if it falls into a certain frequency range, this cannot be taken to indicate that it has any functional dependence on the hippocampus.

## Hippocampal

Due to the density of its neural layers, the hippocampus generates some of the largest EEG signals of any brain structure. In some situations the EEG is dominated by regular waves at 4–10 Hz, often continuing for many seconds. This EEG pattern is known as the *hippocampal theta rhythm*. It has also been called *Rhythmic Slow Activity* (RSA), to contrast it with the *Large Irregular Activity* (LIA) that usually dominates the hippocampal EEG when theta is not present.

In rats, hippocampal theta is seen mainly in two conditions: first, when an animal is running, walking, or in some other way actively interacting with its surroundings; second, during [REM sleep](https://en.wikipedia.org/wiki/Rapid_eye_movement_sleep) ([Vanderwolf, 1969](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refVanderwolf1969)). The frequency of the theta waves increases as a function of running speed, starting at about 6.5 Hz on the low end, and increasing to about 9 Hz at the fastest running speeds, although higher frequencies are sometimes seen for brief high-velocity movements such as jumps across wide gaps. In larger species of animals, theta frequencies are generally lower. The behavioral dependency also seems to vary by species: in cats and rabbits, theta is often observed during states of motionless alertness. This has been reported for rats as well, but only when they are fearful ([Sainsbury et al., 1987](https://en.wikipedia.org/wiki/Theta_rhythm#refSainsbury1987)).

Theta is not just confined to the hippocampus. In rats, it can be observed in many parts of the brain, including nearly all that interact strongly with the hippocampus. The generation of the rhythm is dependent on the medial septal area: this area projects to all of the regions that show theta rhythmicity, and destruction of it eliminates theta throughout the brain ([Stewart & Fox, 1990](https://en.wikipedia.org/wiki/Theta_rhythm#refStewart1990)).

### Type 1 and type 2

In 1975 Kramis, Bland, and Vanderwolf proposed that in rats there are two distinct types of hippocampal theta rhythm, with different behavioral and pharmacological properties ([Kramis et al., 1975](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refKramis1975)). Type 1 ("atropine resistant") theta, according to them, appears during locomotion and other types of "voluntary" behavior and during REM sleep, has a frequency usually around 8 Hz, and is unaffected by the anticholinergic drug [atropine](https://en.wikipedia.org/wiki/Atropine). Type 2 ("atropine sensitive") theta appears during immobility and during anesthesia induced by [urethane](https://en.wikipedia.org/wiki/Ethyl_carbamate), has a frequency in the 4–7 Hz range, and is eliminated by administration of atropine. Many later investigations have supported the general concept that hippocampal theta can be divided into two types, although there has been dispute about the precise properties of each type. Type 2 theta is comparatively rare in unanesthetized rats: it may be seen briefly when an animal is preparing to make a movement but hasn't yet executed it, but has only been reported for extended periods in animals that are in a state of frozen immobility because of the nearby presence of a predator such as a cat or ferret ([Sainsbury et al., 1987](https://en.wikipedia.org/wiki/Theta_rhythm#refSainsbury1987)).

### Relationship with behavior

Vanderwolf ([1969](https://en.wikipedia.org/wiki/Theta_rhythm#refVanderwolf1969)) made a strong argument that the presence of theta in the hippocampal EEG can be predicted on the basis of what an animal is doing, rather than why the animal is doing it. Active movements such as running, jumping, bar-pressing, or exploratory sniffing are reliably associated with theta; inactive states such as eating or grooming are associated with LIA. Later studies showed that theta frequently begins several hundred milliseconds before the onset of movement, and that it is associated with the intention to move rather than with feedback produced by movement ([Whishaw & Vanderwolf, 1973](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refWhishaw1973)). The faster an animal runs, the higher the theta frequency. In rats, the slowest movements give rise to frequencies around 6.5 Hz, the fastest to frequencies around 9 Hz, although faster oscillations can be observed briefly during very vigorous movements such as large jumps.

There is also a distinction between sleep states: REM (dreaming) sleep is associated with theta; slow-wave sleep is associated with LIA.[*[citation needed](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed" \o "Wikipedia:Citation needed)*]

### Mechanisms

Numerous studies have shown that the medial septal area plays a central role in generating hippocampal theta ([Stewart & Fox, 1990](https://en.wikipedia.org/wiki/Theta_rhythm#refStewart1990)). Lesioning the medial septal area, or inactivating it with drugs, eliminates both type 1 and type 2 theta. Under certain conditions, theta-like oscillations can be induced in hippocampal or entorhinal cells in the absence of septal input, but this does not occur in intact, undrugged adult rats. The critical septal region includes the [medial septal nucleus](https://en.wikipedia.org/wiki/Medial_septal_nucleus) and the vertical limb of the [diagonal band of Broca](https://en.wikipedia.org/wiki/Diagonal_band_of_Broca). The lateral septal nucleus, a major recipient of hippocampal output, probably does not play an essential role in generating theta.

The medial septal area projects to a large number of brain regions that show theta modulation, including all parts of the hippocampus as well as the entorhinal cortex, perirhinal cortex, retrosplenial cortex, medial mamillary and supramamillary nuclei of the hypothalamus, anterior nuclei of the thalamus, amygdala, inferior colliculus, and several brainstem nuclei ([Buzsáki, 2002](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refBuzsaki2002)). Some of the projections from the medial septal area are cholinergic; the rest are GABAergic or glutamatergic. It is commonly argued that cholinergic receptors do not respond rapidly enough to be involved in generating theta waves, and therefore that GABAergic and/or glutamatergic signals (Ujfalussy and Kiss, 2006) must play the central role.

A major research problem has been to discover the "pacemaker" for the theta rhythm, that is, the mechanism that determines the oscillation frequency. The answer is not yet entirely clear, but there is some evidence that type 1 and type 2 theta depend on different pacemakers. For type 2 theta, the supramamillary nucleus of the hypothalamus appears to exert control ([Kirk, 1998](https://en.wikipedia.org/wiki/Theta_rhythm#refKirk1998)). For type 1 theta, the picture is still unclear, but the most widely accepted hypothesis proposes that the frequency is determined by a feedback loop involving the medial septal area and hippocampus ([Wang, 2002](https://en.wikipedia.org/wiki/Theta_rhythm#refWang2002)).

Several types of hippocampal and entorhinal neurons are capable of generating theta-frequency membrane potential oscillations when stimulated. Typically these are sodium-dependent voltage-sensitive oscillations in [membrane potential](https://en.wikipedia.org/wiki/Membrane_potential) at near-[action potential](https://en.wikipedia.org/wiki/Action_potential) voltages ([Alonso & Llinás, 1989](https://en.wikipedia.org/wiki/Theta_rhythm#refAlonso1989)). Specifically, it appears that in [neurons](https://en.wikipedia.org/wiki/Neuron) of the CA1 and dentate gyrus, these oscillations result from an interplay of [dendritic](https://en.wikipedia.org/wiki/Dendrite) excitation via a persistent sodium current (*I*NaP) with perisomatic inhibition ([Buzsáki, 2002](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refBuzsaki2002)).

#### Generators

As a rule, EEG signals are generated by synchronized synaptic input to the dendrites of neurons arranged in a layer. The hippocampus contains multiple layers of very densely packed neurons—the [dentate gyrus](https://en.wikipedia.org/wiki/Dentate_gyrus) and the CA3/CA1/subicular layer—and therefore has the potential to generate strong EEG signals. Basic EEG theory says that when a layer of neurons generates an EEG signal, the signal always phase-reverses at some level. Thus, theta waves recorded from sites above and below a generating layer have opposite signs. There are other complications as well: the hippocampal layers are strongly curved, and theta-modulated inputs impinge on them from multiple pathways, with varying phase relationships. The outcome of all these factors is that the phase and amplitude of theta oscillations change in a very complex way as a function of position within the hippocampus. The largest theta waves, however, are generally recorded from the vicinity of the fissure that separates the CA1 molecular layer from the dentate gyrus molecular layer. In rats, these signals frequently exceed 1 [millivolt](https://en.wikipedia.org/wiki/Volt) in amplitude. Theta waves recorded from above the hippocampus are smaller, and polarity-reversed with respect to the fissure signals.

The strongest theta waves are generated by the CA1 layer, and the most significant input driving them comes from the [entorhinal cortex](https://en.wikipedia.org/wiki/Entorhinal_cortex), via the direct EC→CA1 pathway. Another important driving force comes from the CA3→CA1 projection, which is out of phase with the entorhinal input, leading to a gradual phase shift as a function of depth within CA1 ([Brankack, et al. 1993](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refBrankack1993)). The dentate gyrus also generates theta waves, which are difficult to separate from the CA1 waves because they are considerably smaller in amplitude, but there is some evidence that dentate gyrus theta is usually about 90 degrees out of phase from CA1 theta. Direct projections from the septal area to hippocampal interneurons also play a role in generating theta waves, but their influence is much smaller than that of the entorhinal inputs (which are, however, themselves controlled by the septum).

### Research findings

Theta-frequency activity arising from the hippocampus is manifested during some short-term memory tasks ([Vertes, 2005](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refVertes)). Studies suggest that these rhythms reflect the "on-line" state of the hippocampus; one of readiness to process incoming signals ([Buzsáki, 2002](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refBuzsaki2002)). Conversely, theta oscillations have been correlated to various voluntary behaviors (exploration, spatial navigation, etc.) and alert states ([piloerection](https://en.wikipedia.org/wiki/Piloerection" \o "Piloerection), etc.) in rats ([Vanderwolf, 1969](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refVanderwolf1969)), suggesting that it may reflect the integration of sensory information with motor output (for review, see [Bland & Oddie, 2001](https://en.wikipedia.org/wiki/Theta_rhythm#refBland2001)). A large body of evidence indicates that theta rhythm is likely involved in spatial learning and navigation ([Buzsáki, 2005](https://en.wikipedia.org/wiki/Theta_rhythm" \l "refBuzsaki2005)).

Theta rhythms are very strong in [rodent](https://en.wikipedia.org/wiki/Rodent) [hippocampi](https://en.wikipedia.org/wiki/Hippocampi) and [entorhinal](https://en.wikipedia.org/wiki/Entorhinal) cortex during learning and memory retrieval, and are believed to be vital to the induction of [long-term potentiation](https://en.wikipedia.org/wiki/Long-term_potentiation), a potential cellular mechanism of learning and memory. Based on evidence from electrophysiological studies showing that both synaptic plasticity and strength of inputs to hippocampal region CA1 vary systematically with ongoing theta oscillations ([Hyman et al., 2003](https://en.wikipedia.org/wiki/Theta_rhythm#refHyman2003); [Brankack et al., 1993](https://en.wikipedia.org/wiki/Theta_rhythm#refBrankack1993)), it has been suggested that the theta rhythm functions to separate periods of encoding of current sensory stimuli and retrieval of episodic memory cued by current stimuli so as to avoid interference that would occur if encoding and retrieval were simultaneous.

## Humans and other primates

In animals, EEG signals are usually recorded using electrodes implanted in the brain; the majority of theta studies have involved electrodes implanted in the hippocampus. In humans, because invasive studies are not ethically permissible except in some neurological patients, by far the largest number of EEG studies have been conducted using electrodes glued to the scalp. The signals picked up by scalp electrodes are comparatively small and diffuse, and arise almost entirely from the cerebral cortex—the hippocampus is too small and too deeply buried to generate recognizable scalp EEG signals. Human EEG recordings show clear theta rhythmicity in some situations, but because of the technical difficulties, it has been difficult to tell whether these signals have any relationship with the hippocampal theta signals recorded from other species.

In contrast to the situation in rats, where long periods of theta oscillations are easily observed using electrodes implanted at many sites, theta has been difficult to pin down in primates, even when intracortical electrodes have been available. Green and Arduini ([1954](https://en.wikipedia.org/wiki/Theta_rhythm#refGreen1954)), in their pioneering study of theta rhythms, reported only brief bursts of irregular theta in monkeys. Other investigators have reported similar results, although Stewart and Fox ([1991](https://en.wikipedia.org/wiki/Theta_rhythm#refStewart1991)) described a clear 7–9 Hz theta rhythm in the hippocampus of urethane-anesthetized macaques and squirrel monkeys, resembling the type 2 theta observed in urethane-anesthetized rats.

Most of the available information on human hippocampal theta comes from a few small studies of epileptic patients with intracranially implanted electrodes used as part of a treatment plan. In the largest and most systematic of these studies, Cantero *et al.* ([2003](https://en.wikipedia.org/wiki/Theta_rhythm#refCantero2003)) found that oscillations in the 4–7 Hz frequency range could be recorded from both the hippocampus and neocortex. The hippocampal oscillations were associated with REM sleep and the transition from sleep to waking, and came in brief bursts, usually less than a second long. Cortical theta oscillations were observed during the transition from sleep and during quiet wakefulness; however, the authors were unable to find any correlation between hippocampal and cortical theta waves, and concluded that the two processes are probably controlled by independent mechanisms.

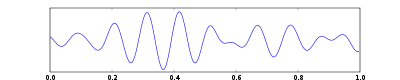
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# Alpha wave

From Wikipedia, the free encyclopedia

Not to be confused with [alpha rays](https://en.wikipedia.org/wiki/Alpha_rays).

For the 3D platform video game, see [Alpha Waves](https://en.wikipedia.org/wiki/Alpha_Waves).

[](https://en.wikipedia.org/wiki/File:Eeg_alpha.svg)

Alpha waves

**Alpha waves** are [neural oscillations](https://en.wikipedia.org/wiki/Neural_oscillations) in the frequency range of 7.5–12.5 [Hz](https://en.wikipedia.org/wiki/Hertz)[[1]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-1) arising from synchronous and coherent (in phase or constructive) electrical activity of [thalamic](https://en.wikipedia.org/wiki/Human_thalamus) pacemaker cells in humans. They are also called [Berger](https://en.wikipedia.org/wiki/Hans_Berger)'s wave in memory of the founder of EEG.

*Alpha waves* are one type of [brain waves](https://en.wikipedia.org/wiki/Neural_oscillations) detected either by [electroencephalography](https://en.wikipedia.org/wiki/Electroencephalography) (EEG) or [magnetoencephalography](https://en.wikipedia.org/wiki/Magnetoencephalography) (MEG) and predominantly originate from the [occipital lobe](https://en.wikipedia.org/wiki/Occipital_lobe) during wakeful relaxation with closed eyes. Alpha waves are reduced with open eyes, drowsiness and sleep. Historically, they were thought to represent the activity of the visual cortex in an idle state. More recent papers have argued that they inhibit areas of the cortex not in use, or alternatively that they play an active role in network coordination and communication.[[2]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-2) Occipital alpha waves during periods of eyes closed are the strongest EEG brain signals.

Alpha waves can be quantified using [Quantitative electroencephalography (qEEG)](https://en.wikipedia.org/wiki/Quantitative_electroencephalography) using freely available toolboxes, such as, [EEGLAB](https://en.wikipedia.org/wiki/EEGLAB) or the [Neurophysiological Biomarker Toolbox](https://en.wikipedia.org/wiki/Neurophysiological_Biomarker_Toolbox).

An alpha-like variant called [mu (μ)](https://en.wikipedia.org/wiki/Mu_rhythm) can be found over the motor cortex (central scalp) that is reduced with movement, or the intention to move. Alpha waves do not start to appear until three years of age.[[3]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-3)

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## History of alpha waves

Alpha waves were discovered by German [neurologist](https://en.wikipedia.org/wiki/Neurologist) [Hans Berger](https://en.wikipedia.org/wiki/Hans_Berger), most famous for his invention of the EEG. Alpha waves were among the first waves documented by Berger, along with [beta waves](https://en.wikipedia.org/wiki/Beta_wave), and he displayed an interest in "alpha blockage", the process by which alpha waves decrease and beta waves increase upon a subject opening their eyes. This distinction earned the alpha wave the alternate title of "Berger's Wave".

Berger took a cue from Russian physiologist [Pravdich-Neminski](https://en.wikipedia.org/wiki/Vladimir_Pravdich-Neminsky), who used a [string galvanometer](https://en.wikipedia.org/wiki/String_galvanometer) to create a photograph of the electrical activity of a dog's brain. Using similar techniques, Berger confirmed the existence of electrical activity in the human brain. He first did this by presenting a stimulus to hospital patients with skull damage and measuring the electrical activity in their brains. Later he ceased the stimulus method and began measuring the natural rhythmic electrical cycles in the brain. The first natural rhythm he documented was what would become known as the alpha wave. Berger was very thorough and meticulous in his data-gathering, but despite his brilliance, he did not feel confident enough to publish his discoveries until at least five years after he had made them. In 1931, he published his first findings on alpha waves in the journal *Archiv für Psychiatrie*. He was originally met with derision for his EEG technique and his subsequent alpha and brain wave discoveries. His technique and findings did not gain widespread acceptance in the psychological community until 1937, when he gained the approval of the famous physiologist [Lord Adrian](https://en.wikipedia.org/wiki/Edgar_Douglas_Adrian,_1st_Baron_Adrian), who took a particular interest in alpha waves.[[4]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-4)

Alpha waves again gained recognition in the early 1960s and 1970s with the creation of a [biofeedback](https://en.wikipedia.org/wiki/Biofeedback) theory relating to brain waves (see below). Such biofeedback, referred to as a kind of [neurofeedback](https://en.wikipedia.org/wiki/Neurofeedback), relating to alpha waves is the conscious elicitation of alpha brainwaves by a subject. Two different researchers in the United States explored this concept through unrelated experiments. Dr. Joe Kamiya, of the University of Chicago, discovered that some individuals had the conscious ability to recognize when they were creating alpha waves, and could increase their alpha activity. These individuals were motivated through a reward system from Kamiya. The second progenitor of biofeedback is Dr. Barry Sterman, from the University of California, Los Angeles. He was working with monitoring brain waves in cats and found that, when the cats were trained to withhold motor movement, they released SMR, or mu, waves, a wave similar to alpha waves. Using a reward system, he further trained these cats to enter this state more easily. Later, he was approached by the United States Air Force to test the effects of a jet fuel that was known to cause seizures in humans. Sterman tested the effects of this fuel on the previously-trained cats, and discovered that they had a higher resistance to seizures than non-trained cats.

Alpha wave biofeedback has gained interest for having some successes in humans for seizure suppression and for treatment of depression.[[5]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-5)

## Types of alpha waves

Some researchers posit that there are at least two forms of alpha waves, which may have different functions in the wake-sleep cycle.

Alpha waves are present at different stages of the wake-sleep cycle. The most widely-researched is during the relaxed mental state, where the subject is at rest with eyes closed, but is not tired or asleep. This alpha activity is centered in the [occipital lobe](https://en.wikipedia.org/wiki/Occipital_lobe), and is presumed to originate there, although there has been recent speculation that it instead has a thalamic origin.[[6]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-6) This wave begins appearing at around four months, and is initially a frequency of 4 waves per second. The mature alpha wave, at 10 waves per second, is firmly established by age 3.[[7]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-7)

The second occurrence of alpha wave activity is during [REM sleep](https://en.wikipedia.org/wiki/Rapid_eye_movement_sleep). As opposed to the awake form of alpha activity, this form is located in a frontal-central location in the brain. The purpose of alpha activity during REM sleep has yet to be fully understood. Currently, there are arguments that alpha patterns are a normal part of REM sleep, and for the notion that it indicates a semi-arousal period. It has been suggested that this alpha activity is inversely related to REM sleep pressure.

It has long been believed that alpha waves indicate a wakeful period during sleep. This has been attributed to studies where subjects report non-refreshing sleep and have EEG records reporting high levels of alpha intrusion into sleep. This occurrence is known as alpha wave intrusion.[[8]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-8) However, it is possible that these explanations may be misleading, as they only focus on alpha waves being generated from the occipital lobe.

## Alpha wave intrusion

Alpha wave intrusion occurs when alpha waves appear with non-REM sleep when delta activity is expected. It is hypothesized to be associated with [fibromyalgia](https://en.wikipedia.org/wiki/Fibromyalgia),[[9]](https://en.wikipedia.org/wiki/Alpha_wave" \l "cite_note-9) although the study may be inadequate due to a small sampling size.

Despite this, alpha wave intrusion has not been significantly linked to any major [sleep disorder](https://en.wikipedia.org/wiki/Sleep_disorder), including fibromyalgia, [chronic fatigue syndrome](https://en.wikipedia.org/wiki/Chronic_fatigue_syndrome), and [major depression](https://en.wikipedia.org/wiki/Major_depression). However, it is common in chronic fatigued patients, and may amplify the effects of other sleep disorders.[[10]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-10)

## Biofeedback training

Because of alpha waves' connection with relaxed mental states, increase in alpha wave activity is a desirable outcome for some types of biofeedback training. EEG can be used to provide the subject with feedback when alpha waves increase, enabling some individuals to consciously increase alpha wave activity.

There are several different prospects of this training that are currently being explored. Arguably, the most popular one is the use of this training in [meditation](https://en.wikipedia.org/wiki/Meditation). Zen-trained meditation masters produce noticeably more alpha waves during meditation. This fact has led to a popular trend of biofeedback training programs for everyday stress relief. Citation: <http://www.abovetopsecret.com/forum/thread711504/pg>

Psychologists are hoping to use this technique to help people overcome [phobias](https://en.wikipedia.org/wiki/Phobia), calm down [hyperactive](https://en.wikipedia.org/wiki/Hyperactivity) children, and help children with [stuttering](https://en.wikipedia.org/wiki/Stuttering) problems to relax enough to practice regular speech.

There are other uses of biofeedback training beyond therapy. Defense Department researchers are exploring biofeedback as a way of getting captured soldiers to create alpha waves, potentially foiling enemy lie detectors. Biofeedback training has also been receiving attention as a possible way of monitoring attention. It has been theorized that teaching machines could use biofeedback as a way of monitoring children's attention, with the appearance of alpha waves signaling a lapse of attention.[[11]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-11)

Following this lapse-of-attention line of thought, a recent study indicates that alpha waves may be used to predict mistakes. In it, MEGs measured increases of up to 25% in alpha brain wave activity before mistakes occurred. This study used common sense: alpha waves indicate idleness, and mistakes are often made when a person is doing something automatically, or "on auto-pilot", and not paying attention to the task they are performing. After the mistake was noticed by the subject, there was a decrease in alpha waves as the subject began paying more attention. This study hopes to promote the use of wireless EEG technology on employees in high-risk fields, such as air traffic controlling, to monitor alpha wave activity and gauge the attention level of the employee.[[12]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-12)

## Alpha wave artifacts

As demonstrated by Adrian Upton, it is possible for extraneous sources (ambient fluctuations detected with a mound of [Jell-O](https://en.wikipedia.org/wiki/Jell-O) in Upton's experiments) to cause signals to appear on an EEG readout, causing false signals to be interpreted as healthy alpha waves. This finding suggests that it is possible that a non-flat EEG could lead to the interpretation that a patient is still living when in fact he or she is long dead.

Cecil Adams from The Straight Dope discusses this scenario:

Sometimes it's claimed Jell-O brainwaves are identical to a healthy adult's. That's clearly a stretch, but the Jell-O EEG readings do look pretty similar to a normal human alpha rhythm. Alpha waves are observed when a patient is awake and resting with eyes closed, and in some kinds of sleep and reversible coma. True, the Jell-O waves are a little slower and of much lower amplitude, barely within normal human limits, but that doesn't tell you much by itself. Hypoxia, encephalitis, and other medical conditions can cause reduced frequency and amplitude, as can drug use.[[13]](https://en.wikipedia.org/wiki/Alpha_wave#cite_note-13)

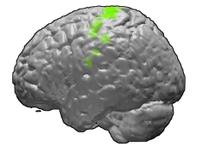
# ~~~~~~~~~~~~~~~

# Mu wave

From Wikipedia, the free encyclopedia

[Single lead EEG readout](https://en.wikipedia.org/wiki/File:Eeg_alpha.svg)

One second sample of an [EEG](https://en.wikipedia.org/wiki/EEG) [alpha wave](https://en.wikipedia.org/wiki/Alpha_wave) recording. This wave occurs at [frequencies](https://en.wikipedia.org/wiki/Frequency) similar to the mu wave, although the alpha wave is detected over a different part of the brain.

[](https://en.wikipedia.org/wiki/File:Motor_cortex.PNG)

The left [motor cortex](https://en.wikipedia.org/wiki/Motor_cortex), or [BA4](https://en.wikipedia.org/wiki/Brodmann_area_4), is highlighted in green on this left [lateral](https://en.wikipedia.org/wiki/Lateral_%28anatomy%29) view of the brain. This is the area over which mu waves are detected [bilaterally](https://en.wiktionary.org/wiki/bilateral).

**Mu waves**, also known as **mu rhythms**, comb or wicket rhythms, arciform rhythms, or [sensorimotor rhythms](https://en.wikipedia.org/wiki/Sensorimotor_rhythm), are synchronized patterns of electrical activity involving large numbers of [neurons](https://en.wikipedia.org/wiki/Neuron), probably of the [pyramidal](https://en.wikipedia.org/wiki/Pyramidal_cell) type, in the part of the brain that controls voluntary movement.[[1]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Amzica-1) These patterns as measured by [electroencephalography](https://en.wikipedia.org/wiki/Electroencephalography) (EEG), [magnetoencephalography](https://en.wikipedia.org/wiki/Magnetoencephalography) (MEG), or [electrocorticography](https://en.wikipedia.org/wiki/Electrocorticography) (ECoG), repeat at a frequency of 7.5–12.5 (and primarily 9–11) [Hz](https://en.wikipedia.org/wiki/Hertz), and are most prominent when the body is physically at rest.[[1]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Amzica-1) Unlike the [alpha wave](https://en.wikipedia.org/wiki/Alpha_wave), which occurs at a similar frequency over the resting [visual cortex](https://en.wikipedia.org/wiki/Visual_cortex) at the back of the scalp, the mu wave is found over the [motor cortex](https://en.wikipedia.org/wiki/Motor_cortex), in a band approximately from ear to ear. A person suppresses mu wave patterns when he or she performs a motor action or, with practice, when he or she visualizes performing a motor action. This suppression is called [desynchronization](https://en.wiktionary.org/wiki/desynchronization) of the wave because EEG wave forms are caused by large numbers of neurons firing in synchrony. The mu wave is even suppressed when one observes another person performing a motor action. Researchers such as [V. S. Ramachandran](https://en.wikipedia.org/wiki/Vilayanur_S._Ramachandran) and colleagues have suggested that this is a sign that the [mirror neuron system](https://en.wikipedia.org/wiki/Mirror_neuron_system) is involved in mu wave suppression,[[2]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Oberman-2)[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3) although others disagree.[[4]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Churchland-4)

The mu wave is of interest to a variety of scholars. Scientists who study [neural development](https://en.wikipedia.org/wiki/Neural_development) are interested in the details of the development of the mu wave in infancy and childhood and its role in learning.[[5]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Nystrom-5) Since a group of researchers believe that [autism spectrum disorder](https://en.wikipedia.org/wiki/Autism_spectrum_disorder) (ASD) is strongly influenced by an altered mirror neuron system[[2]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Oberman-2)[[6]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Bernier-6)[[7]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Williams-7) and that mu wave suppression is a downstream indication of mirror neuron activity,[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3) many of these scientists have kindled a more popular interest in investigating the mu wave in people with ASD. Assorted investigators are also in the process of using mu waves to develop a new technology: the [brain-computer interface](https://en.wikipedia.org/wiki/Brain-computer_interface) (BCI). With the emergence of BCI systems, clinicians hope to give the severely physically disabled population new methods of communication and a means to manipulate and navigate their environments.[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)

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* [2 Development](https://en.wikipedia.org/wiki/Mu_wave#Development)
  + [2.1 Autism](https://en.wikipedia.org/wiki/Mu_wave#Autism)
* [3 Brain-computer interfaces](https://en.wikipedia.org/wiki/Mu_wave#Brain-computer_interfaces)
* [4 History](https://en.wikipedia.org/wiki/Mu_wave#History)
* [5 See also](https://en.wikipedia.org/wiki/Mu_wave#See_also)
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## Mirror neurons

The [mirror neuron system](https://en.wikipedia.org/wiki/Mirror_neuron_system) consists of a class of [neurons](https://en.wikipedia.org/wiki/Neuron) that was first studied in the 1990s in [macaque monkeys](https://en.wikipedia.org/wiki/Macaque_monkey).[[7]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Williams-7) Studies have found sets of neurons that fire when these monkeys perform simple tasks and also when the monkeys view others performing the same simple tasks.[[9]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-di_Pellegrino-9) This suggests they play a role in mapping others' movements into the brain without actually physically performing the movements. These sets of neurons are called mirror neurons and together make up the mirror neuron system. Mu waves are suppressed when these neurons fire, a phenomenon which allows researchers to study mirror neuron activity in humans.[[10]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Rizzolatti-10) There is evidence that mirror neurons exist in humans as well as in non-human animals. The right [fusiform gyrus](https://en.wikipedia.org/wiki/Fusiform_gyrus), left [inferior parietal lobule](https://en.wikipedia.org/wiki/Inferior_parietal_lobule), right anterior [parietal cortex](https://en.wikipedia.org/wiki/Parietal_lobe), and left [inferior frontal gyrus](https://en.wikipedia.org/wiki/Inferior_frontal_gyrus) are of particular interest.[[7]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Williams-7)[[11]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Marshall-11)[[12]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Keuken-12) Some researchers believe that mu wave suppression can be a consequence of mirror neuron activity throughout the brain, and represents a higher-level integrative processing of mirror neuron activity.[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3) Tests in both monkeys (using invasive measuring techniques) and humans (using EEG and [fMRI](https://en.wikipedia.org/wiki/FMRI)) have found that these mirror neurons not only fire during basic motor tasks, but also have components that deal with intention.[[13]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Sinigaglia-13) There is evidence of an important role for mirror neurons in humans, and mu waves may represent a high level coordination of those mirror neurons.[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3)

## Development

A fruitful conceptualization of mu waves in pediatric use that is independent of their frequency is that mu wave suppression is a representation of activity going on in the world, and is detectable in the [frontal](https://en.wikipedia.org/wiki/Frontal_lobe) and [parietal](https://en.wikipedia.org/wiki/Parietal_lobe) networks.[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3) A resting oscillation becomes suppressed during the observation of sensory information such as sounds or sights, usually within the [frontoparietal](https://en.wiktionary.org/wiki/frontoparietal) (motor) cortical region.[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3) Measured in this way, the mu wave is detectable during infancy as early as four to six months, when the peak frequency the wave reaches can be as low as 5.4 [Hz](https://en.wikipedia.org/wiki/Hertz).[[5]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Nystrom-5)[[14]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Berchicci-14) There is a rapid increase in peak frequency in the first year of life,[[14]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Berchicci-14) and by age two frequency typically reaches 7.5 Hz.[[11]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Marshall-11) The peak frequency of the mu wave increases with age until maturation into adulthood, when it reaches its final and stable frequency of 8–13 Hz.[[5]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Nystrom-5)[[11]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Marshall-11)[[14]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Berchicci-14) These varying frequencies are measured as activity around the [central sulcus](https://en.wikipedia.org/wiki/Central_sulcus), within the Rolandic cortex.[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3)

Mu waves are thought to be indicative of an infant’s developing ability to [imitate](https://en.wikipedia.org/wiki/Imitate). This is important because the ability to imitate plays a vital role in the development of [motor skills](https://en.wikipedia.org/wiki/Motor_skill), tool use, and understanding causal information through social interaction.[[11]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Marshall-11) Mimicking is integral in the development of social skills and understanding nonverbal cues.[[5]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Nystrom-5) Causal relationships can be made through social learning without requiring experience firsthand. In action execution, mu waves are present in both infants and adults before and after the execution of a motor task and its accompanying desynchronization. While executing a goal-oriented action, however, infants exhibit a higher degree of desynchronization than do adults. Just as with an action execution, during action observation infants’ mu waves not only show a desynchronization, but show a desynchronization greater in degree than the one evidenced in adults.[[5]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Nystrom-5) This tendency for changes in degree of desynchronization, rather than actual changes in frequency, becomes the measure for mu wave development throughout adulthood, although the most changes take place during the first year of life.[[14]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Berchicci-14) Understanding the mechanisms that are shared between action perception and execution in the earliest years of life has implications for [language development](https://en.wikipedia.org/wiki/Language_development). Learning and understanding through social interaction comes from imitating movements as well as vowel sounds. Sharing the experience of attending to an object or event with another person can be a powerful force in the development of language.[[15]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Meltzoff-15)

### Autism

[Autism](https://en.wikipedia.org/wiki/Autism) is a disorder that is associated with social and communicative deficits. A single cause of autism has yet to be identified, but the mu wave and mirror neuron system have been studied specifically for their role in the disorder. In a typically developing individual, the mirror neuron system responds when he or she either watches someone perform a task or performs the task him- or herself. In individuals with autism, mirror neurons become active (and consequently mu waves are suppressed) only when the individual performs the task him- or herself.[[2]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Oberman-2)[[6]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Bernier-6) This finding has led some scientists, notably [V. S. Ramachandran](https://en.wikipedia.org/wiki/Vilayanur_S._Ramachandran) and colleagues, to view autism as disordered understanding of other individuals' [intentions](https://en.wikipedia.org/wiki/Intention) and [goals](https://en.wikipedia.org/wiki/Goal) thanks to problems with the mirror neuron system.[[7]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Williams-7) This deficiency would explain the difficulty people with autism have in communicating with and understanding others. While most studies of the mirror neuron system and mu waves in people with autism have focused on simple motor tasks, some scientists speculate that these tests can be expanded to show that problems with the mirror neuron system underlie overarching [cognitive](https://en.wikipedia.org/wiki/Cognitive_deficit) and [social](https://en.wikipedia.org/wiki/Social_skills) deficits.[[2]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Oberman-2)[[6]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Bernier-6)

Based on findings correlating mirror neuron activity and mu wave suppression in individuals with autism as in typically developing individuals,[[16]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda2-16) studies have examined both the development of mirror neurons and therapeutic means for stimulating the system. A recent study has found that [fMRI](https://en.wikipedia.org/wiki/FMRI) activation magnitudes in the [inferior frontal gyrus](https://en.wikipedia.org/wiki/Inferior_frontal_gyrus) increase with age in people with autism. This finding was not apparent in typically developing individuals. Furthermore, greater activation was associated with greater amounts of eye contact and better [social functioning](https://en.wikipedia.org/wiki/Social_functioning).[[17]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Bastiaansen-17) Scientists believe the inferior frontal gyrus is one of the main neural correlates with the mirror neuron system in humans and is often related to deficits associated with autism.[[12]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Keuken-12) These findings suggest that the mirror neuron system may not be non-functional in individuals with autism, but simply abnormal in its development. This information is significant to the present discussion because mu waves may be integrating different areas of mirror neuron activity in the brain.[[3]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pineda3-3) Other studies have assessed attempts to consciously stimulate the mirror neuron system and suppress mu waves using [neurofeedback](https://en.wikipedia.org/wiki/Neurofeedback) (a type of [biofeedback](https://en.wikipedia.org/wiki/Biofeedback) given through computers that analyze real time recordings of brain activity, in this case EEGs of mu waves). This type of therapy is still in its early phases of implementation for individuals with autism, and has conflicting forecasts for success.[[18]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Holtmann-18)[[19]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Coben-19)

## Brain-computer interfaces

[Brain-computer interfaces](https://en.wikipedia.org/wiki/Brain-computer_interface) (BCIs) are a developing technology that clinicians hope will one day bring more independence and agency to the severely physically disabled. Those the technology has the potential to help include people with near-total or total paralysis, such as those with [tetraplegia](https://en.wikipedia.org/wiki/Tetraplegia) (quadriplegia) or advanced [amyotrophic lateral sclerosis](https://en.wikipedia.org/wiki/Amyotrophic_lateral_sclerosis) (ALS); BCIs are intended to help them to communicate or even move objects such as motorized wheelchairs, [neuroprostheses](https://en.wikipedia.org/wiki/Neuroprostheses), or robotic grasping tools.[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)[[20]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Machado-20) Few of these technologies are currently in regular use by people with disabilities, but a diverse array are in development at an experimental level.[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)[[21]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller2-21)[[22]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Leuthardt-22) One type of BCI uses event-related desynchronization (ERD) of the mu wave in order to control the computer.[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8) This method of monitoring brain activity takes advantage of the fact that when a group of neurons is at rest they tend to fire in synchrony with each other. When a participant is cued to imagine movement (an "event"), the resulting desynchronization (the group of neurons that was firing in synchronous waves now firing in complex and individualized patterns) can be reliably detected and analyzed by a computer. Users of such an interface are trained in visualizing movements, typically of the foot, hand, and/or tongue, which are each in different locations on the [cortical homunculus](https://en.wikipedia.org/wiki/Cortical_homunculus) and thus distinguishable by an [electroencephalograph](https://en.wikipedia.org/wiki/Electroencephalography) (EEG) or [electrocorticograph](https://en.wikipedia.org/wiki/Electrocorticograph) (ECoG) recording of electrical activity over the [motor cortex](https://en.wikipedia.org/wiki/Motor_cortex).[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)[[21]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller2-21) In this method, computers monitor for a typical pattern of mu wave ERD [contralateral](https://en.wikipedia.org/wiki/Contralateral) to the visualized movement combined with event-related synchronization (ERS) in the surrounding tissue.[[21]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller2-21) This paired pattern intensifies with training,[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)[[21]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller2-21)[[22]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Leuthardt-22)[[23]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Allison-23) and the training increasingly takes the form of games, some of which utilize [virtual reality](https://en.wikipedia.org/wiki/Virtual_reality).[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)[[21]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller2-21)[[23]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Allison-23) Some researchers have found that the feedback from virtual reality games is particularly effective in giving the user tools to improve control of his or her mu wave patterns.[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)[[23]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Allison-23) The ERD method can be combined with one or more other methods of monitoring the brain's electrical activity to create hybrid BCIs, which often offer more flexibility than a BCI that uses any single monitoring method.[[8]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller1-8)[[21]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-Pfurtscheller2-21)

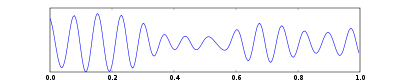
## History

Mu waves have been studied since the 1930s, and are referred to as the wicket rhythm because the rounded EEG waves resemble [croquet wickets](https://en.wikipedia.org/wiki/Croquet). In 1950, [Henri Gastaut](https://en.wikipedia.org/wiki/Henri_Gastaut) and his coworkers reported desynchronization of these waves not only during active movements of their subjects, but also while the subjects observed actions executed by someone else.[[24]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r1-24)[[25]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r2-25) These results were later confirmed by additional research groups,[[26]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-The_blocking_of_the_Rolandic_wicket_rhythm_and_some_central_changes_related_to_movement-26)[[27]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r3-27)[[28]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r4-28)[[29]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r5-29) including a study using [subdural](https://en.wiktionary.org/wiki/subdural) [electrode](https://en.wikipedia.org/wiki/Electrode) grids in [epileptic](https://en.wikipedia.org/wiki/Epileptic) patients.[[30]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r6-30) The latter study showed mu suppression while the patients observed moving body parts in [somatic](https://en.wikipedia.org/wiki/Somatic_nervous_system) areas of the cortex that corresponded to the body part moved by the actor. Further studies have shown that the mu waves can also be desynchronized by imagining actions[[31]](https://en.wikipedia.org/wiki/Mu_wave" \l "cite_note-r7-31)[[32]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r8-32) and by passively viewing point-light [biological motion](https://en.wikipedia.org/wiki/Biological_motion).[[33]](https://en.wikipedia.org/wiki/Mu_wave#cite_note-r9-33)

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# Sensorimotor rhythm

From Wikipedia, the free encyclopedia

[](https://en.wikipedia.org/wiki/File:Eeg_SMR.svg)

SMR waves

The **sensorimotor rhythm** (SMR) is [brain wave](https://en.wikipedia.org/wiki/Neural_oscillation) rhythm. It is an oscillatory idle rhythm of synchronized electromagnetic brain activity. It appears in spindles in recordings of [EEG](https://en.wikipedia.org/wiki/EEG), [MEG](https://en.wikipedia.org/wiki/Magnetoencephalography), and [ECoG](https://en.wikipedia.org/wiki/ECoG) over the [sensorimotor cortex](https://en.wikipedia.org/wiki/Motor_cortex). For most individuals, the frequency of the SMR is in the range of 13 to 15 Hz.[[1]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-1)

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* [3 See also](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#See_also)
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* [4 References](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#References)
* [5 Further reading](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#Further_reading)

## Meaning

The meaning of SMR is not fully understood. Phenomenologically, a person is producing a stronger SMR amplitude when the corresponding sensorimotor areas are idle, e.g. during states of immobility. SMR typically decrease in amplitude when the corresponding sensory or [motor](https://en.wikipedia.org/wiki/Motor_system) areas are activated, e.g. during motor tasks and even during motor imagery.[[2]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-2)

Conceptually, SMR is sometimes mixed up with [alpha waves](https://en.wikipedia.org/wiki/Alpha_wave) of occipital origin, the strongest source of neural signals in the EEG. One reason might be, that without appropriate spatial filtering the SMR is very difficult to detect as it is usually superimposed by the stronger occipital alpha waves. The feline SMR has been noted as being analogous to the human [mu rhythm](https://en.wikipedia.org/wiki/Mu_rhythm).[[3]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-3)

## Relevance in research

### Neurofeedback

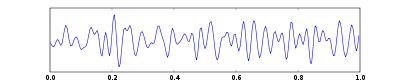
[Neurofeedback](https://en.wikipedia.org/wiki/Neurofeedback) training can be used to gain control over the SMR activity. Neurofeedback practitioners believe—and have produced experimental evidence to back up their claims[[4]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm" \l "cite_note-4)—that this feedback enables the subject to learn the regulation of their own SMR. People with [learning difficulties](https://en.wikipedia.org/wiki/Learning_disability),[[5]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-5) [ADHD](https://en.wikipedia.org/wiki/ADHD),[[6]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-6) [epilepsy](https://en.wikipedia.org/wiki/Epilepsy),[[7]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-7) and [autism](https://en.wikipedia.org/wiki/Autism)[[8]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-8) may benefit from an increase in SMR activity via [neurofeedback](https://en.wikipedia.org/wiki/Neurofeedback). In the field of [Brain-Computer Interfaces (BCI)](https://en.wikipedia.org/wiki/Brain-computer_interface), the deliberate modification of the SMR amplitude during motor imagery can be used to control external applications.[[9]](https://en.wikipedia.org/wiki/Sensorimotor_rhythm#cite_note-9)

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# Beta wave

From Wikipedia, the free encyclopedia

Not to be confused with [beta rays](https://en.wikipedia.org/wiki/Beta_rays).

[](https://en.wikipedia.org/wiki/File:Eeg_beta.svg)

Beta waves

**Beta wave**, or beta rhythm, is the term used to designate the [frequency](https://en.wikipedia.org/wiki/Frequency) range of [human brain](https://en.wikipedia.org/wiki/Human_brain) activity between 12.5 and 30 [Hz](https://en.wikipedia.org/wiki/Hertz) (12.5 to 30 transitions or cycles per second). Beta waves are split into three sections: Low Beta Waves (12.5–16 Hz, "Beta 1 power"); Beta Waves (16.5–20 Hz, "Beta 2 power"); and High Beta Waves (20.5–28 Hz, "Beta 3 power").[[1]](https://en.wikipedia.org/wiki/Beta_wave#cite_note-1) Beta states are the states associated with normal waking consciousness. Beta waves can be quantified using [Quantitative electroencephalography (qEEG)](https://en.wikipedia.org/wiki/Quantitative_electroencephalography) using freely available toolboxes, such as, [EEGLAB](https://en.wikipedia.org/wiki/EEGLAB) or the [Neurophysiological Biomarker Toolbox](https://en.wikipedia.org/wiki/Neurophysiological_Biomarker_Toolbox).

## Contents

* [1 Function](https://en.wikipedia.org/wiki/Beta_wave#Function)
* [2 See also](https://en.wikipedia.org/wiki/Beta_wave#See_also)
  + [2.1 Brain waves](https://en.wikipedia.org/wiki/Beta_wave#Brain_waves)
* [3 References](https://en.wikipedia.org/wiki/Beta_wave#References)

## Function

Low amplitude beta waves with multiple and varying frequencies are often associated with active, busy, or anxious thinking and active concentration.[[2]](https://en.wikipedia.org/wiki/Beta_wave#cite_note-2)

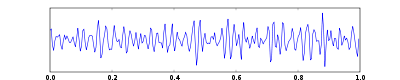
Over the [motor cortex](https://en.wikipedia.org/wiki/Motor_cortex) beta waves are associated with the [muscle contractions](https://en.wikipedia.org/wiki/Muscle_contraction) that happen in [isotonic](https://en.wikipedia.org/wiki/Isotonic_%28exercise_physiology%29) movements and are suppressed prior to and during movement changes.[[3]](https://en.wikipedia.org/wiki/Beta_wave#cite_note-3) Bursts of beta activity are associated with a strengthening of sensory feedback in static motor control and reduced when there is movement change.[[4]](https://en.wikipedia.org/wiki/Beta_wave#cite_note-4) Beta activity is increased when movement has to be resisted or voluntarily suppressed.[[5]](https://en.wikipedia.org/wiki/Beta_wave#cite_note-5) The artificial induction of increased beta waves over the motor cortex by a form of electrical stimulation called [Transcranial alternating-current stimulation](https://en.wikipedia.org/wiki/Transcranial_alternating_current_stimulation) consistent with its link to isotonic contraction produces a slowing of motor movements.[[6]](https://en.wikipedia.org/wiki/Beta_wave#cite_note-6)

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# Gamma wave

From Wikipedia, the free encyclopedia

Not to be confused with [gamma rays](https://en.wikipedia.org/wiki/Gamma_rays).

[](https://en.wikipedia.org/wiki/File:Eeg_gamma.svg)

Gamma waves

A **gamma wave** is a pattern of [neural oscillation](https://en.wikipedia.org/wiki/Neural_oscillation) in humans with a frequency between 25 and 100 [Hz](https://en.wikipedia.org/wiki/Hertz),[[1]](https://en.wikipedia.org/wiki/Gamma_wave" \l "cite_note-Hughes-1) though 40 Hz is typical.[[2]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-gold-2)

According to a popular theory, gamma waves may be implicated in creating the unity of conscious [perception](https://en.wikipedia.org/wiki/Perception) (the [binding problem](https://en.wikipedia.org/wiki/Binding_problem)).[[3]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-buzsaki-3)[[4]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-pollack-4)[[5]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-singer-5) However, there is no agreement on the theory; as a researcher suggests:

Whether or not gamma wave activity is related to subjective awareness is a very difficult question which cannot be answered with certainty at the present time.[[6]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-vanderwolf-6)

## Contents

* [1 History](https://en.wikipedia.org/wiki/Gamma_wave#History)
* [2 Linked to unity of consciousness?](https://en.wikipedia.org/wiki/Gamma_wave#Linked_to_unity_of_consciousness.3F)
  + [2.1 History of idea](https://en.wikipedia.org/wiki/Gamma_wave#History_of_idea)
  + [2.2 Role in attentive focus](https://en.wikipedia.org/wiki/Gamma_wave#Role_in_attentive_focus)
  + [2.3 Contemporary research](https://en.wikipedia.org/wiki/Gamma_wave#Contemporary_research)
  + [2.4 Relation to meditation](https://en.wikipedia.org/wiki/Gamma_wave#Relation_to_meditation)
  + [2.5 Opposing evidence](https://en.wikipedia.org/wiki/Gamma_wave#Opposing_evidence)
* [3 See also](https://en.wikipedia.org/wiki/Gamma_wave#See_also)
  + [3.1 Brain waves](https://en.wikipedia.org/wiki/Gamma_wave#Brain_waves)
* [4 References](https://en.wikipedia.org/wiki/Gamma_wave#References)
* [5 Further reading](https://en.wikipedia.org/wiki/Gamma_wave#Further_reading)
* [6 External links](https://en.wikipedia.org/wiki/Gamma_wave#External_links)

## History

Gamma waves were initially ignored before the development of digital [electroencephalography](https://en.wikipedia.org/wiki/Electroencephalography) as analog electroencephalography is restricted to recording and measuring rhythms that are usually less than 25 Hz.[[1]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-Hughes-1) One of the earliest reports on them was in 1964 using recordings of the electrical activity of electrodes implanted in the visual cortex of awake monkeys.[[7]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-7)

## Linked to unity of consciousness?

### History of idea

The idea that distinct regions in the brain were being stimulated simultaneously was suggested by the finding in 1988[[2]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-gold-2) that two neurons oscillate synchronously (though they are not directly connected) when a single external object stimulates their respective receptive fields. Subsequent experiments by many others demonstrated this phenomenon in a wide range of visual cognition. In particular, [Francis Crick](https://en.wikipedia.org/wiki/Francis_Crick) and [Christof Koch](https://en.wikipedia.org/wiki/Christof_Koch) in 1990[[8]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-8) argued that there is a significant relation between the binding problem and the problem of visual consciousness and, as a result, that synchronous 40 Hz oscillations may be causally implicated in visual awareness as well as in visual binding. Later the same authors expressed scepticism over the idea that 40 Hz oscillations are a sufficient condition for visual awareness.[[9]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-9)

A lead article by [Andreas K. Engel](https://en.wikipedia.org/wiki/Andreas_K._Engel) *et al*. in the journal *Consciousness and Cognition* (1999) that argues for temporal synchrony as the basis for consciousness, defines the gamma wave hypothesis thus: [[10]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-10)

The hypothesis is that synchronization of neuronal discharges can serve for the integration of distributed neurons into cell assemblies and that this process may underlie the selection of perceptually and behaviorally relevant information.

### Role in attentive focus

The suggested mechanism is that gamma waves relate to neural consciousness via the mechanism for conscious attention:

The proposed answer lies in a wave that, originating in the thalamus, sweeps the brain from front to back, 40 times per second, drawing different neuronal circuits into synch with the [precept](https://en.wikipedia.org/wiki/Precept), and thereby bringing the precept into the attentional foreground. If the thalamus is damaged even a little bit, this wave stops, conscious awarenesses do not form, and the patient slips into profound coma.[[4]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-pollack-4)

Thus the claim is that when all these neuronal clusters oscillate together during these transient periods of synchronized firing, they help bring up memories and associations from the visual precept to other notions. This brings a [distributed matrix](https://en.wikipedia.org/w/index.php?title=Distributed_matrix&action=edit&redlink=1) of cognitive processes together to generate a coherent, concerted cognitive act, such as perception. This has led to theories that gamma waves are associated with solving the [binding problem](https://en.wikipedia.org/wiki/Binding_problem).[[3]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-buzsaki-3)

Gamma waves are observed as [neural synchrony](https://en.wikipedia.org/wiki/Neural_oscillations) from visual cues in both conscious and [subliminal](https://en.wikipedia.org/wiki/Unconscious_mind) stimuli.[[11]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-11)[[12]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-12)[[13]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-13) [[14]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-14) This research also sheds light on how neural synchrony may explain [stochastic resonance](https://en.wikipedia.org/wiki/Stochastic_resonance) in the nervous system.[[15]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-15) Gamma Waves are also implicated during [Rapid eye movement](https://en.wikipedia.org/wiki/Rapid_eye_movement_sleep) sleep and anesthesia, which involves visualizations.[[6]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-vanderwolf-6)

### Contemporary research

A 2009 study published in Nature successfully induced gamma waves in mice brains. Researchers performed this study using [optogenetics](https://en.wikipedia.org/wiki/Optogenetics) (the method of combining genetic engineering with light to manipulate the activity of individual nerve cells). The protein channelrhodopsin-2 (ChR2), which sensitizes cells to light, was genetically engineered into these mice, specifically to be expressed in a target-group of interneurons. These fast-spiking (FS) interneurons, known for high electrical activity, were then activated with an optical fiber and laser—the second step in optogenetics. In this way, the cell activity of these interneurons was manipulated in the frequency range of 8–200 Hz. The study produced empirical evidence of gamma wave induction in the approximate interval of 25–100 Hz. The gamma waves were most apparent at a frequency of 40 Hz; this indicates that the gamma waves evoked by FS manipulation are a resonating brain circuit property. This is the first study in which it has been shown that a brain state can be induced through the activation of a specific group of cells.[[16]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-16)

### Relation to meditation

Experiments on [Tibetan](https://en.wikipedia.org/wiki/Tibetan_people) [Buddhist](https://en.wikipedia.org/wiki/Buddhist) monks have shown a correlation between transcendental mental states and gamma waves.[[17]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-O.27Nuallain-17)[[18]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-18) A suggested explanation is based on the fact that the gamma is intrinsically localized. Neuroscientist Sean O'Nuallain suggests that this very existence of synchronized gamma indicates that something akin to a singularity - or, to be more prosaic, a conscious experience - is occurring.[[17]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-O.27Nuallain-17) This work adduces experimental and simulated data to show that what meditation masters have in common is the ability to put the brain into a state in which it is maximally sensitive.

As hinted above, gamma waves have been observed in Tibetan Buddhist monks. A 2004 study took eight long-term Tibetan Buddhist practitioners of meditation and, using electrodes, monitored the patterns of electrical activity produced by their brains as they meditated. The researchers compared the brain activity of the monks to a group of novice meditators (the study had these subjects meditate an hour a day for one week prior to empirical observation). In a normal meditative state, both groups were shown to have similar brain activity. However, when the monks were told to generate an objective feeling of compassion during meditation, their brain activity began to fire in a rhythmic, coherent manner, suggesting neuronal structures were firing in harmony. This was observed at a frequency of 25–40 Hz, the rhythm of gamma waves. These gamma-band oscillations in the monk’s brain signals were the largest seen in humans (apart from those in states such as seizures). Conversely, these gamma-band oscillations were scant in novice meditators. Though, a number of rhythmic signals did appear to strengthen in beginner meditators with further experience in the exercise, implying that the aptitude for one to produce gamma-band rhythm is trainable.[[19]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-19)

Such evidence and research in gamma-band oscillations may explain the heightened sense of consciousness, bliss, and intellectual acuity subsequent to meditation. Notably, meditation is known to have a number of health benefits: stress reduction, mood elevation, and increased life expectancy of the mind and its cognitive functions. The current [Dalai Lama](https://en.wikipedia.org/wiki/14th_Dalai_Lama) meditates for four hours each morning, and he says that it is hard work. He elaborates that if neuroscience can construct a way in which he can reap the psychological and biological rewards of meditation without going through the practice each morning, he would be apt to adopt the innovation.[[20]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-20)

### Opposing evidence

Many neuroscientists are not convinced of the gamma wave argument. Arguments against it range from the possibility of mismeasurement – it has been suggested that EEG-measured gamma waves could be in many cases an artifact of electromyographic activity[[21]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-pmid17574912-21)[[22]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-pmid18329954-22) – to relations to other neural function, such as minute eye movements.[[23]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-pmid18466752-23)

However, proponents like O'Nuallain and Andreas Engel argue that gamma evidence persists even with careful signal separation.[[17]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-O.27Nuallain-17)[[24]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-24)

Moreover, recent studies using [magnetoencephalography](https://en.wikipedia.org/wiki/Magnetoencephalography) (MEG), which does not suffer the potential artifacts associated with EEG, have identified gamma activity associated with sensory processing, mainly in the [visual cortex](https://en.wikipedia.org/wiki/Visual_cortex).[[25]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-25)[[26]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-26)[[27]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-27)[[28]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-28)

Bearing this theory in mind, a number of questions remain unexplained regarding details of exactly how the temporal synchrony results in a conscious awareness or how a new percept "calls for"[[4]](https://en.wikipedia.org/wiki/Gamma_wave#cite_note-pollack-4) the synchrony, etc.

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**External links**

* [SCNN's EEGLAB Page](http://sccn.ucsd.edu/eeglab)

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  | | --- | --- | | [**Electroencephalography (EEG)**](https://en.wikipedia.org/wiki/Electroencephalography) | | |  | | | **Related tests** | * [Event-related potential](https://en.wikipedia.org/wiki/Event-related_potential) * [Electrocorticography (ECoG)](https://en.wikipedia.org/wiki/Electrocorticography) * [Magnetoencephalography (MEG)](https://en.wikipedia.org/wiki/Magnetoencephalography) * [Somatosensory evoked potential](https://en.wikipedia.org/wiki/Somatosensory_evoked_potential) * [Brainstem auditory evoked potential](https://en.wikipedia.org/wiki/Brainstem_auditory_evoked_potential) | |  | | | [**Evoked potentials**](https://en.wikipedia.org/wiki/Evoked_potential) | Negativity  [Bereitschaftspotential](https://en.wikipedia.org/wiki/Bereitschaftspotential)  [ELAN](https://en.wikipedia.org/wiki/Early_left_anterior_negativity)  [N100](https://en.wikipedia.org/wiki/N100)  [Visual N1](https://en.wikipedia.org/wiki/Visual_N1)  [N170](https://en.wikipedia.org/wiki/N170)  [N200](https://en.wikipedia.org/wiki/N200_%28neuroscience%29)  [N2pc](https://en.wikipedia.org/wiki/N2pc)  [N400](https://en.wikipedia.org/wiki/N400_%28neuroscience%29)  [Contingent negative variation (CNV)](https://en.wikipedia.org/wiki/Contingent_negative_variation)  [Mismatch negativity](https://en.wikipedia.org/wiki/Mismatch_negativity)  Positivity  [C1 & P1](https://en.wikipedia.org/wiki/C1_and_P1_%28neuroscience%29)  [P50](https://en.wikipedia.org/wiki/P50_%28neuroscience%29)  [P200](https://en.wikipedia.org/wiki/P200)  [P300](https://en.wikipedia.org/wiki/P300_%28neuroscience%29)  [P3a](https://en.wikipedia.org/wiki/P3a)  [P3b](https://en.wikipedia.org/wiki/P3b)  [P600](https://en.wikipedia.org/wiki/P600_%28neuroscience%29) (late positivity)  [Late positive component](https://en.wikipedia.org/wiki/Late_positive_component) | |  | | | [**Neural oscillations**](https://en.wikipedia.org/wiki/Neural_oscillation) | * [Alpha wave](https://en.wikipedia.org/wiki/Alpha_wave) * [Beta wave](https://en.wikipedia.org/wiki/Beta_wave) * [Gamma wave](https://en.wikipedia.org/wiki/Gamma_wave) * [Delta wave](https://en.wikipedia.org/wiki/Delta_wave) * [Theta rhythm](https://en.wikipedia.org/wiki/Theta_rhythm) * [K-complex](https://en.wikipedia.org/wiki/K-complex) * [Sleep spindle](https://en.wikipedia.org/wiki/Sleep_spindle) * [Sensorimotor rhythm](https://en.wikipedia.org/wiki/Sensorimotor_rhythm) * [Mu wave](https://en.wikipedia.org/wiki/Mu_wave) | |  | | | **Topics** | * [10-20 system](https://en.wikipedia.org/wiki/10-20_system_%28EEG%29) * [Difference due to memory (Dm)](https://en.wikipedia.org/wiki/Difference_due_to_memory) * [Oddball paradigm](https://en.wikipedia.org/wiki/Oddball_paradigm) * **EEGLAB** * [Neurophysiological Biomarker Toolbox (NBT)](https://en.wikipedia.org/wiki/Neurophysiological_Biomarker_Toolbox) | |

[Categories](https://en.wikipedia.org/wiki/Help:Category):

* [Free mathematics software](https://en.wikipedia.org/wiki/Category:Free_mathematics_software)
* [Magnetoencephalography](https://en.wikipedia.org/wiki/Category:Magnetoencephalography)
* [Electroencephalography](https://en.wikipedia.org/wiki/Category:Electroencephalography)

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http://sccn.ucsd.edu/eeglab/

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# EEGLAB

From Wikipedia, the free encyclopedia

**EEGLAB** is a [MATLAB](https://en.wikipedia.org/wiki/MATLAB) toolbox distributed under the free [GNU](https://en.wikipedia.org/wiki/GNU) [GPL](https://en.wikipedia.org/wiki/GPL) license for processing data from [electroencephalography](https://en.wikipedia.org/wiki/Electroencephalography) (EEG), [magnetoencephalography](https://en.wikipedia.org/wiki/Magnetoencephalography) (MEG), and other electrophysiological signals. Along with all the basic processing tools, EEGLAB implements [independent component analysis](https://en.wikipedia.org/wiki/Independent_component_analysis) (ICA), time/frequency analysis, artifact rejection, and several modes of data visualization. EEGLAB allows users to import their electrophysiological data in about 20 binary file formats, preprocess the data, visualize activity in single trials, and perform ICA. Artifactual ICA components may be subtracted from the data. Alternatively, ICA components representing brain activity may be further processed and analyzed. EEGLAB also allows users to group data from several subjects, and to cluster their independent components.

## Contents

* [1 History](https://en.wikipedia.org/wiki/EEGLAB#History)
* [2 Statistics](https://en.wikipedia.org/wiki/EEGLAB#Statistics)
* [3 See also](https://en.wikipedia.org/wiki/EEGLAB#See_also)
* [4 Sources](https://en.wikipedia.org/wiki/EEGLAB#Sources)
* [5 External links](https://en.wikipedia.org/wiki/EEGLAB#External_links)

## History

In 1997, a set of data processing functions was first released on the Internet by Scott Makeig in the Computational Neurobiology Laboratory directed by Terry Sejnowski at the [Salk Institute](https://en.wikipedia.org/wiki/Salk_Institute), under the name “the ICA/EEG toolbox”. In 2000, [Arnaud Delorme](https://en.wikipedia.org/wiki/Arnaud_Delorme) designed a [graphical user interface](https://en.wikipedia.org/wiki/Graphical_user_interface) on top of these functions along with some of his own artifact removal functions, and released the first version of the “EEGLAB software for artifact removal”. In 2003, Delorme and Makeig joined efforts to release the first stable and fully documented version of EEGLAB. In 2004, EEGLAB was awarded funding by the [NIH](https://en.wikipedia.org/wiki/NIH) for continued development of research software.

## Statistics

EEGLAB was downloaded about 25,000 times from 73 countries worldwide in its first three years (2003–2006) and in 2011 was reported to be the most widely used signal processing environment for processing of EEG data by cognitive neuroscientists ([survey results](http://neuro.debian.net/survey/2011/results.html)). Its reference paper (Delorme & Makeig, 2004) has received over [2,300 citations](http://scholar.google.com/scholar?oi=bibs&hl=en&cites=6160226079476557314) (02/2013).

EEGLAB comprises over 380 stand-alone MATLAB functions and over 50,000 lines of code and hosts over 20 user-contributed plug-ins. Significant plug-in toolboxes continue to be written and published by researchers at the Swartz Center, UCSD, and by many other groups. Major plug-ins include:

* DIPFIT, for source localization of ICA component sources of EEG data;
* FMRIB for removal of fMRI artifacts in EEG data;
* [FASTER](http://sourceforge.net/projects/faster/), a fully automated, unsupervised method for processing high density EEG data;
* [ERPLAB](http://erpinfo.org/erplab), for deriving measures from average event-related potentials;
* [NBT](http://www.nbtwiki.net/), a toolbox for the computation and integration of neurophysiological biomarkers;
* [NFT](http://sccn.ucsd.edu/wiki/NFT), for building electrical forward head models from MR images and/or electrode positions;
* [SIFT](http://sccn.ucsd.edu/wiki/SIFT), a source information flow toolbox;
* [BCILAB](http://sccn.ucsd.edu/wiki/BCILAB), an extensive environment for building and testing brain-computer interface models;
* [MPT](http://sccn.ucsd.edu/wiki/MPT), a toolbox for performing measure projection of group EEG source data into a template head; etc.

Hundreds of researchers have contributed directly or indirectly to the software by programming functions or reporting bugs. The current eeglablist email discussion list has over 4,000 members worldwide (2013).

## See also

[The EEGLAB Home Page](http://sccn.ucsd.edu/eeglab);

|  |  |
| --- | --- |
| [Portal icon](https://en.wikipedia.org/wiki/File:Nuvola_apps_emacs_vector.svg) | [***Free software portal***](https://en.wikipedia.org/wiki/Portal:Free_software) |

A Delorme & S Makeig. "EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics," Journal of Neuroscience Methods 134:9-21 (2004)

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