

# Magnetoencephalography (MEG)

Authored by  
**mohammad looti**

October 1, 2025

## RECOMMENDED CITATION

mohammad looti (2025). *Magnetoencephalography (MEG)*. PSYCHOLOGICAL SCALES.  
Retrieved from <https://scales.arabpsychology.com/?p=32041>

## Magnetoencephalography (MEG)

**Primary Disciplinary Field(s):** Neuroscience, Clinical Neurology, Cognitive Science, Biomedical Engineering, Physics

### 1. Core Definition

Magnetoencephalography (MEG) is an advanced, non-invasive neuroimaging technique employed to measure the faint magnetic fields generated by electrical currents occurring naturally in the brain. This sophisticated methodology provides a direct and highly precise means of monitoring brain activity, distinguishing itself through its exceptional temporal resolution, which allows for the detection of neuronal signals on a millisecond-by-millisecond basis. By capturing these minute magnetic fluctuations, MEG offers a dynamic window into the intricate workings of the brain, far surpassing many other techniques in its ability to track rapid neural events.

The fundamental principle behind MEG lies in the fact that the synchronized electrical activity of large populations of neurons, specifically the postsynaptic currents within cortical pyramidal cells, produces measurable magnetic fields external to the scalp. These magnetic fields, though extremely weak--typically orders of magnitude smaller than the Earth's magnetic field--are detectable by highly sensitive sensors known as Superconducting Quantum Interference Devices (SQUIDs). The capacity of MEG to accurately specify both the timing and the location of these neuronal signals makes it an invaluable tool for both basic neuroscience research and clinical applications, providing critical insights into various perceptual, cognitive, and pathological brain mechanisms.

### 2. Historical Development and Physical Principles

The concept of detecting magnetic fields from the brain emerged in the late 1960s. The first successful MEG measurement was made in 1968 by David Cohen, who used a single-channel room-temperature induction coil to detect alpha rhythms. However, the extreme faintness of these biological magnetic fields necessitated the development of extraordinarily sensitive detectors. This challenge was largely overcome with the advent of SQUIDs in the 1970s, which could operate at cryogenic temperatures to achieve the required sensitivity. The integration of SQUIDs into multi-channel systems marked a significant leap, transforming MEG from a theoretical possibility into a practical brain imaging modality.

The physical basis of MEG is rooted in electromagnetism. When neurons fire, they generate intracellular electrical currents. These currents produce magnetic fields that obey the right-hand rule, meaning the magnetic field lines circulate around the direction of the current flow. Crucially, MEG is primarily sensitive to magnetic fields generated by intracellular currents that flow tangential to the scalp surface, which typically originate from neurons located in the cortical sulci. Fields

generated by radial currents, which are perpendicular to the scalp, produce magnetic fields that largely cancel out or are too weak to be detected externally, a characteristic that differentiates MEG from Electroencephalography (EEG), which is sensitive to both radial and tangential current sources.

### 3. Working Mechanism: Detecting Magnetic Fields

The operational mechanism of an MEG system involves several sophisticated components working in concert. The core of the system is a helmet-shaped array of SQUID sensors, which are housed within a magnetically shielded room to minimize interference from environmental magnetic noise (e.g., from power lines, electronic devices, or even cars). These SQUIDS are cooled to extremely low temperatures (around 4 Kelvin) using liquid helium, a necessity for their superconducting properties which enable them to detect magnetic fields on the order of femtoteslas (10<sup>-15</sup> Tesla). This unparalleled sensitivity allows the system to distinguish the minute magnetic signals emanating from the brain from the much stronger ambient magnetic noise.

When a subject performs a cognitive task or is presented with a sensory stimulus, the synchronized electrical activity of neuronal populations in the brain generates weak magnetic fields. These fields pass unimpeded through the skull and scalp, unlike electrical potentials which are distorted by these tissues. The SQUID sensors pick up these magnetic signals, which are then amplified and digitized. Sophisticated computational algorithms are subsequently applied to reconstruct the neural sources that generated these magnetic fields. This inverse problem in MEG involves estimating the location, orientation, and strength of the active neuronal sources within the brain based on the magnetic field distribution measured outside the head, often in conjunction with structural images obtained from Magnetic Resonance Imaging (MRI) for precise anatomical localization.

### 4. Key Characteristics and Advantages

MEG possesses several distinct characteristics that confer significant advantages over other neuroimaging techniques. Firstly, it is entirely **non-invasive**, meaning it does not involve radiation exposure, injections of tracers, or direct contact with the brain, making it safe for repeated use in both clinical and research settings, including studies with children and vulnerable populations. This safety profile is a major benefit for longitudinal studies and clinical diagnostics where repeated measurements are often necessary to track disease progression or treatment efficacy.

Secondly, MEG offers unparalleled **temporal resolution**, capable of capturing brain activity with millisecond precision. This allows researchers to track the rapid sequence of neural events underlying various cognitive processes, such as perception, attention, memory, and language. Unlike fMRI, which measures blood flow changes (a slower metabolic response), MEG directly

measures neuronal activity, providing a more immediate and accurate reflection of brain function. Coupled with its good **spatial resolution**, particularly for cortical sources, MEG can localize the active brain regions responsible for specific functions with considerable accuracy, often within a few millimeters, making it highly valuable for detailed brain mapping.

Furthermore, because magnetic fields are less distorted than electrical potentials when passing through brain tissue, skull, and scalp, MEG offers a more accurate localization of current sources compared to EEG. The magnetic fields are not significantly attenuated or smeared by these tissues, providing a clearer "view" of the underlying neural generators. This characteristic contributes to MEG's strength in pre-surgical planning, where precise localization of eloquent cortex or epileptic foci is paramount to minimize surgical risks and optimize patient outcomes.

## 5. Applications in Research and Clinical Practice

The unique capabilities of MEG have made it an indispensable tool across various domains of neuroscience and clinical neurology. In basic research, MEG is extensively used to investigate fundamental cognitive mechanisms. For example, it helps delineate the neural pathways involved in sensory processing (e.g., auditory, visual, somatosensory), language comprehension and production, decision-making, and the dynamics of attention. By precisely identifying when and where different brain regions become active during these tasks, researchers can construct detailed spatiotemporal maps of brain function, advancing our understanding of healthy brain operation.

In clinical settings, one of the most critical applications of MEG is in **pre-surgical mapping**, particularly for patients with intractable epilepsy or brain tumors. For epilepsy patients, MEG can accurately localize the epileptogenic zone, the specific brain region where seizures originate. This information is crucial for neurosurgeons to precisely target the tissue for removal, minimizing damage to healthy brain areas responsible for vital functions like movement, speech, or sensation. Similarly, for patients undergoing surgery for brain tumors, MEG can map the location of eloquent cortex (areas essential for motor, sensory, or language functions) relative to the tumor, allowing surgeons to plan their approach to preserve critical functions and avoid post-operative deficits.

Beyond these established applications, MEG is also playing an increasingly important role in understanding and diagnosing a wide range of neurological and psychiatric disorders. Its ability to detect subtle abnormalities in brain activity patterns makes it suitable for investigating conditions like Alzheimer's disease, Parkinson's disease, autism spectrum disorder, and concussion. By identifying biomarkers of disease or tracking the impact of therapeutic interventions, MEG contributes to both research into disease mechanisms and the development of more effective treatments.

## 6. MEG in Neurological and Psychiatric Disorders

MEG's sensitivity to transient and localized brain activity makes it exceptionally valuable for studying various neurological and psychiatric conditions. For instance, in the context of schizophrenia, MEG has been instrumental in revealing unique neurological responses and aberrant brain network dynamics. Studies using MEG have identified disruptions in gamma-band oscillations, which are crucial for cognitive processes such as perception, memory, and attention, in patients with schizophrenia. These findings suggest that the integration of information across different brain regions is impaired, contributing to the characteristic symptoms of the disorder, such as hallucinations and delusions.

Furthermore, MEG research has shed light on sensory processing deficits in schizophrenia, showing altered responses to auditory and visual stimuli at very early stages of processing. For example, reduced magnetic evoked fields in response to auditory clicks can indicate abnormalities in the auditory cortex, potentially underlying auditory hallucinations. By precisely localizing these dysfunctional areas and quantifying the timing of these altered responses, MEG provides critical insights into the pathophysiology of schizophrenia, potentially paving the way for more targeted diagnostic markers and therapeutic strategies that aim to restore normal neural synchrony.

Beyond schizophrenia, MEG contributes significantly to research on other neurodevelopmental and neurodegenerative disorders. In autism spectrum disorder, MEG has revealed atypical patterns of brain connectivity and altered responses to social and linguistic stimuli, suggesting differences in how information is integrated across brain regions. For Alzheimer's disease, MEG studies have identified changes in brain oscillations, such as a slowing of alpha rhythms and an increase in theta activity, which correlate with cognitive decline. These findings highlight MEG's potential not only for deeper understanding of these complex conditions but also for developing early diagnostic tools and monitoring disease progression.

## 7. Limitations and Challenges

Despite its numerous advantages, Magnetoencephalography is not without its limitations and challenges. One significant constraint is its **cost**; MEG systems are expensive to purchase, install, and maintain, typically requiring specialized facilities like magnetically shielded rooms and a continuous supply of liquid helium for cooling the SQUIDs. This high operational cost limits its widespread availability, making it primarily accessible in major research institutions and specialized clinical centers. The need for a dedicated, noise-free environment also adds to the logistical complexity and expense.

Another limitation relates to its **spatial resolution for deeper brain structures**. While MEG offers excellent spatial resolution for cortical sources (especially those in the sulci, tangential to the scalp), its sensitivity decreases rapidly with distance from the sensors. Consequently, it is less

effective at detecting activity from deep brain structures such as the thalamus, brainstem, or hippocampus compared to techniques like fMRI. This is due to the inverse square law of magnetic fields and the orientation sensitivity of MEG, which favors tangential currents near the scalp surface.

Furthermore, the **inverse problem** in MEG, which involves localizing the neural sources from the measured magnetic fields, is mathematically ill-posed. This means that multiple source configurations could potentially produce the same magnetic field distribution at the scalp, requiring the use of sophisticated computational models and assumptions to estimate the most probable source locations. While significant progress has been made in source localization algorithms, the accuracy can still be influenced by factors such as individual head anatomy, the signal-to-noise ratio, and the complexity of the neural activity being measured.

## 8. Comparison with Other Neuroimaging Techniques

MEG occupies a unique niche among neuroimaging modalities due to its specific strengths when compared to techniques like EEG, fMRI, and Positron Emission Tomography (PET). While EEG also measures direct neuronal activity with high temporal resolution, MEG offers superior spatial localization. This is because magnetic fields pass through the skull and scalp largely undistorted, whereas electrical potentials detected by EEG are significantly smeared and attenuated by these tissues, making source localization more challenging and less precise for EEG. Both EEG and MEG provide direct measures of neuronal activity, contrasting with fMRI and PET.

Functional Magnetic Resonance Imaging (fMRI) provides excellent spatial resolution, capable of localizing activity in deep brain structures, but its temporal resolution is inherently limited by the sluggish nature of the blood-oxygen-level-dependent (BOLD) response, which is an indirect measure of neuronal activity. While fMRI can pinpoint "where" activity occurs with great precision, it struggles to determine "when" it occurs with the same millisecond accuracy as MEG. Conversely, PET, which measures metabolic activity or neurotransmitter binding using radioactive tracers, also offers good spatial resolution but very poor temporal resolution and involves exposure to ionizing radiation.

The complementary strengths of these techniques often lead to their combined use in research. For instance, combining MEG's high temporal resolution with fMRI's high spatial resolution allows researchers to precisely localize brain activity in both space and time, providing a more comprehensive picture of brain function. This multimodal approach leverages the best features of each technique, compensating for their individual limitations and offering deeper insights into complex neural processes and disorders.

## 9. Future Directions and Advancements

The field of Magnetoencephalography continues to evolve, with ongoing research focused on enhancing its capabilities and expanding its applications. One significant area of development involves improving sensor technology. While SQUIDs remain the gold standard, efforts are being made to develop optically pumped magnetometers (OPMs) which can operate without cryogenic cooling, potentially reducing system costs and simplifying operation. OPM-MEG systems could also allow for more flexible sensor placement, conforming better to individual head shapes, which might lead to better signal quality and improved spatial resolution, particularly for pediatric populations.

Another promising direction is the advancement of source localization algorithms and computational modeling. Researchers are continuously refining methods to solve the inverse problem with greater accuracy and less reliance on simplifying assumptions. The integration of advanced machine learning techniques and more sophisticated biophysical models holds the potential to extract even richer information from MEG data, enabling more precise mapping of brain networks and the identification of subtle abnormalities in connectivity or oscillatory patterns.

Ultimately, future developments aim to make MEG more accessible, more robust, and even more informative. As technology progresses, MEG is poised to further cement its role as a leading tool for understanding the brain's dynamic activity, from basic neuroscience investigations to the diagnosis and monitoring of complex neurological and psychiatric conditions, continuing to offer unprecedented insights into the human mind.

### Further Reading

[Magnetoencephalography - Wikipedia](#)

[Superconducting Quantum Interference Device \(SQUID\) - Wikipedia](#)

[Neuroimaging - Wikipedia](#)

[Epilepsy - Wikipedia](#)

[Schizophrenia - Wikipedia](#)

[Functional Magnetic Resonance Imaging \(fMRI\) - Wikipedia](#)

[Electroencephalography \(EEG\) - Wikipedia](#)