A Comprehensive Review of Magnetoencephalography

M. Ramhe*

Department of Radiology and Engineering, Shiraz University, Shiraz, Iran

**Author for correspondence*

ramhe99@mq.ir

Review Article

Magnetoencephalography is a non-invasive technique that measures oscillatory magnetic fields produced in the brain due to neuronal activity with excellent temporal and reasonable amount of spatial resolution at the cellular level; neurons have electrochemical properties that lead to the flow of electrically charged ions and subsequently generation of electromagnetic fields [1]. The magnetic field generated by an individual neuron is very weak, but multiple neurons combined in a specific area produce a field that is measurable outside the head. This neuromagnetic field is in the range of 10–15 T (femtotesla, fT) for cortical activities. Magnetic field follows Ampere's "right-hand rule," with the field directed outward on one side and inward on the other side of a tangentially oriented source current, forming a characteristic dipolar pattern in magnetic field sensors near the scalp. Radially oriented (with respect to the skull surface) source currents generate negligible magnetic field outside the head. Therefore, MEG is mainly sensitive to tangentially oriented sources in sulcal walls. Neuromagnetic fields are captured using highly sensitive superconducting sensors, called SQUIDs (Superconducting Quantum Interference Device). Activity from deeper cortical and subcortical areas is difficult to detect as they exist at longer distance from the sensors. SQUID systems are typically composed of two types sensors, called as magnetometer and gradiometer [2]. Magnetometers measure magnetic field directly, and gradiometers as pairs of magnetometers positioned at a small distance form one another, calculate the difference in the magnetic field between their two locations, are used in MEG data acquisition.

These magnetic fields are produced simultaneously with electrical activity, MEG captures same millisecond resolution as EEG (Electroencephalography), allowing to examine neural activity at its natural temporal resolution [3]. Thus, MEG provides a more direct measure of neuronal activity than functional magnetic resonance imaging (fMRI), which records blood-oxygen-level dependent (BOLD) responses. Oscillatory brain signals are commonly categorized into five frequency bands: Delta (0.2-3 Hz), Theta (4–7 Hz), Alpha (8–13 Hz), Beta (14-31 Hz), and Gamma (32–100 Hz). Each band is associated with different physiological information involving brain activities. Delta (δ) waves are accompanied with deep levels of relaxation and restorative sleep. It has been found that δ waves are associated with unconscious tasks of the body. Irregular δ waves have been connected to awareness as well as learning difficulties. Theta (θ) waves are mostly linked with sleep and it may occur during deep meditation also and it is the associated to memory, intuition, and learning. Alpha (α) waves are associated with resting state oscillations and awaken brain and it aids overall mental coordination, calmness, alertness, intelligence and cognitive abilities.

Beta (β) waves are dominant during attentive cognitive task in normal conscious state. "Fast" activities of β waves are observed in concentration, decision making, anxiety and excitement. Gamma (γ) waves are interrelated to simultaneous processing of information flow from various brain regions. γ frequency is above the neuronal firing range. Presence of γ is associated to cognizance. Among these existing band waves certain bands are associated with cognitive decline [4].

References

1. Cohen D. Magnetoencephalography: evidence of magnetic fields produced by alpha-rhythm currents. *Science* 161, 784-786 (1968).
2. Hillebrand A, Barnes GR. Beamformer analysis of MEG data. *Int Rev Neurobiol* 68, 149-171 (2005).
3. https://pubmed.ncbi.nlm.nih.gov/7473358/
4. Leuchter AF, Newton TF, Cook IA, Walter DO, Rosenberg-Thompson S, Lachenbruch PA. Changes in brain functional connectivity in Alzheimer-type and multi-infarct dementia. *Brain* 115, 1543-1561 (1992).