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Combining EEG and FMRI: Advances in multimodal brain network analysis.

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Introduction

Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are two of the most widely used techniques in human brain research, each offering unique strengths that complement the other. EEG provides high temporal resolution, capturing brain activity on the millisecond scale, which is critical for studying fast neural dynamics. fMRI, in contrast, offers high spatial resolution and can map brain activity across the entire brain with millimeter precision through blood-oxygen-level-dependent (BOLD) signals. By combining EEG and fMRI in multimodal studies, researchers can leverage the temporal precision of EEG with the spatial specificity of fMRI to gain a more complete picture of brain network organization. This integration has been instrumental in advancing our understanding of how distributed brain regions interact over time, offering insights into both healthy brain function and pathological conditions such as epilepsy, schizophrenia, and neurodegenerative diseases [1].

A major advance in combining EEG and fMRI has been the development of hardware and methodological solutions for simultaneous acquisition. Simultaneous EEG-fMRI involves recording EEG signals inside the MRI scanner while acquiring BOLD images, allowing the direct linking of electrophysiological and hemodynamic responses. This approach, however, presents significant technical challenges. EEG signals recorded inside the MRI scanner are contaminated by large gradient artifacts and ballistocardiogram artifacts caused by the magnetic environment and subject physiology. Over the past decade, advanced artifact removal algorithms and improved MR-compatible EEG caps have significantly enhanced the quality of EEG data collected in the scanner. These developments have enabled researchers to relate EEG-derived measures, such as oscillatory power or event-related potentials, to corresponding changes in brain activity detected by fMRI, opening new opportunities for precise mapping of neural processes [2].

The integration of EEG and fMRI has provided valuable insights into brain network dynamics across various cognitive and clinical domains. For example, in studies of resting-state networks, EEG can detect fluctuations in specific frequency bands, such as alpha or gamma rhythms, and fMRI can reveal the spatial networks associated with these fluctuations. In cognitive neuroscience, this multimodal approach has been used to explore how large-scale networks reconfigure during attention, memory, and language

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tasks. In clinical research, simultaneous EEG-fMRI has been particularly powerful in epilepsy, where interictal epileptiform discharges detected in EEG can be mapped to their hemodynamic correlates, helping to localize seizure foci for surgical planning. Beyond epilepsy, multimodal studies have been applied to disorders of consciousness, psychiatric conditions, and neurodevelopmental disorders, yielding a richer understanding of network-level abnormalities that may not be apparent from either modality alone [3].

Recent advances in data analysis techniques have further strengthened the ability to combine EEG and fMRI effectively. Machine learning algorithms, Bayesian inference frameworks, and dynamic causal modeling have been applied to integrate multimodal datasets and infer causal relationships between brain regions. Joint independent component analysis (jICA) and canonical correlation analysis (CCA) have been used to uncover patterns of brain activity shared between EEG and fMRI, while more recent deep learning approaches can learn complex nonlinear mappings between the two modalities. Graph-theoretical approaches have also been employed to characterize brain network topology, allowing the temporal information from EEG to be fused with the spatially detailed connectivity maps derived from fMRI. These computational innovations have expanded the interpretative power of multimodal brain network analysis, moving beyond simple correlation to mechanistic models of brain function [4].

Despite these promising developments, challenges remain in fully realizing the potential of EEG-fMRI integration. One significant issue is the inherent difference in the signals: EEG measures direct electrical activity, while fMRI measures indirect hemodynamic responses that lag behind neural events by several seconds. This temporal mismatch complicates the direct alignment of signals. Moreover, the complexity of multimodal data demands large, high-quality datasets and sophisticated preprocessing pipelines to ensure robust results. Standardization of acquisition protocols, preprocessing methods, and analysis pipelines across laboratories is still a work in progress, and variability in methodology can limit reproducibility. Additionally, simultaneous EEG-fMRI setups are costly and technically demanding, which may limit access for some research groups. Addressing these challenges will be crucial for the broader adoption and translation of EEG-fMRI integration into both basic and clinical neuroscience [5].

Conclusion

The combination of EEG and fMRI has emerged as a powerful approach for multimodal brain network analysis, uniting the high temporal resolution of electrophysiological recordings with the high spatial resolution of hemodynamic imaging. Advances in hardware, artifact correction, and computational modeling have enabled researchers to simultaneously capture the dynamics and spatial organization of brain networks, offering unprecedented insights into neural processes in health and disease. Applications range from cognitive neuroscience studies to clinical diagnostics, particularly in epilepsy and other network-related brain disorders. While challenges related to signal integration, methodological standardization, and resource demands remain, ongoing innovations in acquisition and analysis are steadily enhancing the feasibility and impact of EEG-fMRI research. As these approaches mature, they hold the promise of transforming our understanding of brain network dynamics and providing new avenues for diagnosis and intervention in neurological and psychiatric conditions.

References

1. Boulton AJ. The pathway to foot ulceration in diabetes. Med Clin North Am. 2013;97(5):775-90.
2. Kumar S, Ashe HA, Parnell LN, et al. The prevalence of foot ulceration and its correlates in type 2 diabetic patients: A population?based study. Diabet Med. 1994;11(5):480-4.

Citation: Kovalenko O. Combining EEG and FMRI: Advances in multimodal brain network analysis. J NeuroInform Neuroimaging. 2025;10(2):187.

3. Vileikyte L, Leventhal H, Gonzalez JS, et al. Diabetic peripheral neuropathy and depressive symptoms: The association revisited. Diabetes care. 2005;28(10):2378-83.
4. Albers JW, Pop-Busui R. Diabetic neuropathy: Mechanisms, emerging treatments, and subtypes. Curr Neurol Neurosci Rep. 2014;14:1-1.
5. Partanen J, Niskanen L, Lehtinen J, et al. Natural history of peripheral neuropathy in patients with non-insulin-dependent diabetes mellitus. N Engl J Med. 1995;333(2):89-94.

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