

# International Conference on Cancer Science, Diagnosis and Therapeutics (ICCSDT 2025)

Conference Proceedings

November 28, 2025 Japan

## Disrupted Neuroimmune Pathways in Cognitive Development: Insights from EEG-Based AI Detection of Synaptic and Lymphatic Dysfunctions

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### Abstract

Emerging evidence suggests that disrupted synaptic pruning, chronic microglial activation, and impaired brain lymphatic clearance represent converging neuroimmune mechanisms underlying atypical cognitive development. These processes, fundamental for maintaining neural circuit homeostasis, are particularly vulnerable during critical periods of brain maturation and are increasingly implicated in neurodevelopmental and neurodegenerative disorders.

This review synthesizes recent findings on how deficits in microglial-mediated synapse elimination and glymphatic drainage can lead to sustained neuroinflammation, aberrant connectivity, and cognitive dysfunction. Traditional imaging and behavioral assessment tools often fail to capture these early and subtle disruptions. However, non-invasive electroencephalography (EEG) has emerged as a valuable biomarker platform for quantifying neurophysiological alterations linked to these immune-related processes.

We present evidence from our prior EEG studies demonstrating distinct oscillatory patterns—particularly in the delta, theta, and alpha bands—correlated with immune dysregulation. Moreover, we discuss how artificial intelligence (AI)-based classification algorithms, including artificial neural networks (ANN) and deep learning frameworks, can detect neuroinflammatory signatures in EEG data with high sensitivity, enabling early screening and personalized interventions.

By integrating neuroimmune biology with AI-enhanced electrophysiology, this work proposes a novel diagnostic paradigm for understanding and addressing brain-based cognitive vulnerabilities, with implications for both cancer-related cognitive impairment and developmental disorders.