A Biophysical and Electromagnetic Perspective on Brain Function and Mental Disease

J.Konstapel, Leiden, 11-1-2026.

Contemporary neuroscience has been dominated by biochemical and molecular explanations of brain function. Neurotransmitters, receptors, genes, and signaling cascades form the standard explanatory toolkit for cognition and psychopathology. While this framework has delivered substantial insights, it remains incomplete. The brain is not only a chemical system but fundamentally an electrodynamic one. A biophysical, and specifically electromagnetic (EM), perspective reframes neural function as the organization of matter and energy through fields, rhythms, and coherence, with biochemistry acting as a stabilizing and constraining layer rather than the primary driver.

The Brain as an Electromagnetic Organ

Neurons are excitable cells whose defining feature is the controlled movement of electrical charge across membranes. Action potentials, synaptic currents, and dendritic integration generate time-varying electric and magnetic fields. At the scale of neural populations, these fields are measurable as local field potentials, EEG, and MEG signals. Importantly, these fields are not epiphenomenal. They reflect, and in turn influence, the timing and probability of neuronal firing through ephaptic coupling and field-mediated synchronization.

From a biophysical standpoint, cognition emerges from large-scale coordination of oscillatory activity across spatial and temporal scales. Information is encoded not only in firing rates, but in phase relationships, resonance patterns, and cross-frequency coupling. The brain operates as a metastable system, poised near criticality, where small perturbations can reorganize global dynamics without collapsing into noise or rigidity.

Fields, Plasticity, and Structural Consolidation

Neuroplasticity, typically framed biochemically, can be reinterpreted as the material consolidation of electromagnetic patterns. Repeated, coherent neural activity produces stable field configurations. These configurations bias future activity by lowering energetic thresholds for synchronized firing. Molecular processes such as calcium signaling, CREB activation, and BDNF-mediated synaptic growth function to “lock in” these preferred energetic states.

BDNF is particularly relevant in this context. Rather than acting merely as a growth factor, it can be viewed as a biophysical amplifier that stabilizes synapses participating in coherent network activity. Synaptic strengthening corresponds to changes in dendritic spine geometry, cytoskeletal stiffness, and membrane conductivity—physical properties that directly affect local electric field propagation. Memory, in this sense, is the persistence of field-favorable structures.

Mental Disorders as Disorders of Field Organization

Mental illnesses appear less as localized chemical deficits and more as disorders of global electromagnetic organization.

Depression illustrates this clearly. Neuroimaging and electrophysiological studies consistently show altered large-scale network dynamics: reduced frontal alpha asymmetry, impaired fronto-limbic coupling, and diminished signal complexity. The depressed brain is active but poorly resonant. It occupies a low-entropy attractor state characterized by rigid, self-reinforcing patterns. Reduced BDNF expression follows naturally, as insufficient coherent activity fails to trigger structural consolidation of adaptive circuits.

Alzheimer's disease provides an even more striking example. Long before extensive neuronal death, patients exhibit disrupted theta–gamma coupling and reduced long-range coherence. From an EM perspective, this suggests an early failure of integrative field dynamics. Amyloid-β plaques and tau tangles may be better understood as secondary physical manifestations of a system that can no longer maintain coherent electromagnetic organization. As network synchrony degrades, the biochemical machinery loses its guiding constraints, leading to pathological aggregation.

Schizophrenia, bipolar disorder, and epilepsy similarly show characteristic disturbances in oscillatory coordination and phase synchronization, reinforcing the view that psychiatric diagnoses correspond to distinct regimes of field instability rather than isolated molecular errors.

Implications for Treatment

A biophysical framework reshapes how interventions are interpreted. Pharmacological agents may work less by "correcting deficits" and more by altering excitability and noise levels, enabling the system to re-enter more coherent dynamic regimes. Physical exercise, sleep, and sensory rhythm all act as global EM modulators, enhancing synchrony and signal-to-noise ratios.

Non-invasive brain stimulation techniques such as TMS and tACS are particularly revealing. Their efficacy, modest but reproducible, supports the notion that externally applied fields can entrain endogenous dynamics and indirectly restore biochemical balance. The EM perspective suggests that future therapies will increasingly focus on timing, rhythm, and coherence rather than molecular specificity alone.

Conclusion

A biophysical and electromagnetic view of the brain does not reject biochemistry; it contextualizes it. Mental function arises from the organized flow of energy and information across neural tissue, with molecules serving to stabilize, constrain, and remember field dynamics. Mental disorders, accordingly, are best understood as disruptions of large-scale electromagnetic organization, with molecular pathology emerging downstream. This perspective offers a unifying framework capable of integrating physiology, cognition, and psychopathology at a systems level.

Annotated References

Buzsáki, G. (2006). *Rhythms of the Brain*. Oxford University Press.
Foundational work on neural oscillations and their role in cognition. Provides empirical grounding for viewing brain function as rhythmically organized field activity.

Fries, P. (2015). "Rhythms for Cognition: Communication through Coherence." *Neuron*, 88(1), 220–235.
Demonstrates how phase synchronization enables effective information transfer, supporting the EM coordination framework.

McFadden, J. (2020). "Integrating Information in the Brain's EM Field." *Neuroscience of Consciousness*.
Explicitly argues for causal roles of electromagnetic fields in brain function, offering a theoretical basis for field-based explanations.

Deco, G., Jirsa, V. K., & McIntosh, A. R. (2011). "Emerging Concepts for the Dynamical Organization of Resting-State Activity." ***Nature Reviews Neuroscience*****, 12, 43–56.**
Describes metastability and criticality in large-scale brain networks, central concepts for a biophysical approach.

Palva, J. M., & Palva, S. (2012). "Discovering Oscillatory Interaction Networks." ***Trends in Cognitive Sciences*****, 16(4), 219–230.**
Links oscillatory coupling to cognitive integration and psychiatric vulnerability.

Poo, M. M. et al. (2016). "What Is Memory?" ***Neuron*****, 92(1), 1–5.**
Frames memory as a multiscale physical process, compatible with field-based consolidation via plasticity mechanisms.

Uhlhaas, P. J., & Singer, W. (2010). "Abnormal Neural Oscillations and Synchrony in Schizophrenia." ***Nature Reviews Neuroscience*****, 11, 100–113.**
Illustrates how psychiatric disorders manifest as disruptions in neural synchrony rather than localized lesions.

Stam, C. J. et al. (2009). "Graph Theoretical Analysis of MEG Data in Alzheimer's Disease." ***Brain*****, 132, 213–224.**
Shows early network and coherence breakdown in Alzheimer's, supporting a field-disintegration hypothesis.

Park, H., & Poo, M. M. (2013). "Neurotrophin Regulation of Neural Circuit Development and Function." ***Nature Reviews Neuroscience*****, 14, 7–23.**
Details BDNF's role in activity-dependent plasticity, enabling reinterpretation as a field-stabilizing factor.

Varela, F., Lachaux, J. P., Rodriguez, E., & Martinerie, J. (2001). "The Brainweb." ***Nature Reviews Neuroscience*****, 2, 229–239.**
Seminal systems-level account of large-scale phase synchronization as the basis of cognitive integration.

These works collectively support a shift from molecule-centric explanations toward a biophysical understanding of brain and mind grounded in electromagnetic organization.

Microglia as Biophysical Regulators of Electromagnetic Brain Dynamics

Within a biophysical and electromagnetic framework, microglial cells are often underestimated because they are primarily classified as immune cells. From a field-based perspective, however, they play a fundamental regulatory role in shaping the conditions under which stable electromagnetic organization can emerge and be maintained. Microglia do not directly encode cognitive content, but modulate the material and energetic context in which neural field patterns arise.

Microglia continuously monitor synaptic activity and network dynamics. Their sensitivity to aberrant firing patterns, reduced synchronization, and increased noise effectively positions them as detectors of failing electromagnetic coherence. When large-scale oscillatory organization deteriorates, microglial function shifts from maintenance to activation, resulting in synaptic pruning, cytokine release, and alterations of the extracellular ionic environment.

These processes have direct biophysical consequences. Synaptic density, dendritic geometry, and extracellular conductivity jointly determine how electric fields propagate locally and globally. Excessive or chronic microglial activation disrupts these parameters, increases dissipation, and lowers the capacity for phase locking and resonance. Neuroinflammation, in this context, can be understood as a state in which neural tissue loses its field-supporting properties.

In neuropsychiatric disorders, this dynamic becomes particularly evident. In conditions such as depression and schizophrenia, characterized by rigid or chaotic attractor states, microglial activation can be interpreted as a response to prolonged incoherent network activity. Rather than facilitating recovery, sustained activation contributes to further flattening of field gradients and a reduction in dynamical flexibility.

In neurodegenerative diseases such as Alzheimer's disease, microglial function also fits naturally within a field-disintegration model. Early disturbances in long-range coherence and cross-frequency coupling undermine electromagnetic integration across networks. Microglia respond with clearance and inflammatory mechanisms that, in the absence of restored coherence, lead to structural changes that further constrain remaining field organization. Amyloid-β plaques and tau tangles thus appear not as primary causes, but as downstream manifestations of a system that has lost its electromagnetic integrity.

From this perspective, microglial cells act as biophysical feedback elements: they translate disturbances in electromagnetic organization into structural and chemical reconfigurations of the neural substrate. Their role is therefore fully consistent with the central thesis of this work: biochemical and cellular processes primarily serve to stabilize, correct, or, when coherence fails, dismantle field patterns. Microglia occupy the interface where electromagnetic dynamics and material reorganization converge.