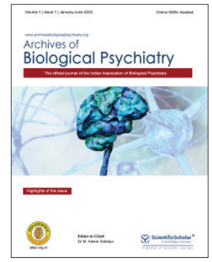
www.archivesbiologicalpsychiatry.org

ScientificScholar® Knowledge is power
Publisher of Scientific Journals

Archives of Biological Psychiatry



Editorial

Artificial intelligence and neuromodulation: A new frontier in psychiatry

M. Aleem Siddiqui[1], Shobit Garg[2]

[1]Department of Psychiatry, Era's Lucknow Medical College and Hospital, Lucknow, Uttar Pradesh, [2]Department of Psychiatry, Shri Guru Ram Rai Institute of Medical and Health Sciences, Dehradun, Uttarakhand, India

***Corresponding author:**
Dr. M. Aleem Siddiqui,
Department of Psychiatry,
Era's Lucknow Medical College and Hospital, Lucknow,
Uttar Pradesh, India.

docaleem@gmail.com

Received: 07 March 2025
Accepted: 07 March 2025
Published: 15 March 2025

DOI
10.25259/ABP_3_2025

Quick Response Code:

The convergence of artificial intelligence (AI) and neuromodulation heralds a transformative era in mental health. Still grappling with the complexities of treatment-resistant disorders, we are acutely aware of the limitations of conventional therapies. Neuromodulation techniques such as transcranial magnetic stimulation (TMS), deep brain stimulation (DBS), and transcranial direct current stimulation do offer hope, but their efficacy remains inconsistent. Enter AI: A tool poised to refine targeting, personalize protocols, and unlock predictive insights. This editorial explores the promises, challenges, and ethical imperatives of this synergy, urging cautious optimism as we navigate this frontier.

THE CURRENT STATE OF NEUROMODULATION: PROGRESS AND PITFALLS

Neuromodulation techniques like TMS have had Food and Drug Administration approval for conditions such as major depressive disorder, obsessive-compulsive disorder (OCD), migraine with aura and nicotine cessation, and DBS, a lifeline for severe OCD, exemplify progress[1]. Yet, challenges persist. Variable patient responses, imperfect targeting, and a "one-size-fits-all" approach limit outcomes. For instance, only 50–60% of TMS patients achieve remission, and DBS requires invasive, often trial-and-error parameter adjustments. These gaps underscore the need for innovation – a role AI is uniquely equipped to fill.[2]

AI AS A CATALYST FOR PRECISION AND PERSONALIZATION

AI's strength lies in decoding complexity. By analyzing multimodal data (neuroimaging, genetics, electronic health records, and real-time biomarkers), machine learning (ML) models can identify patterns invisible to the human eye. Consider these applications:

1. Predictive analytics: ML algorithms can forecast which patients will respond to TMS or DBS, optimizing candidacy selection. Studies have demonstrated that AI-driven analysis of functional magnetic resonance imaging (MRI) data predicted TMS response in depression with greater accuracy than that of clinician assessments.[3]
2. Personalized targeting: AI can map individual neurocircuitry aberrations. For example, Stanford's SAINT protocol uses functional MRI-guided AI to personalize TMS targets, achieving remission in 79% of participants in recent trials leap from traditional methods.
3. Dynamic optimization: Real-time AI analysis of electroencephalogram or wearable data could adjust stimulation parameters mid-treatment. Imagine a DBS system that

adapts to a patient's neural state, akin to responsive neurostimulation in epilepsy.

Such advancements promise to replace empiricism with precision, tailoring interventions to the biological signatures of each patient.

CLOSED-LOOP SYSTEMS: THE NEXT EVOLUTION

Current neuromodulation operates in "open-loop" systems-static settings unchanging from session to session. AI enables closed-loop systems that respond dynamically to neural feedback. Early examples exist in epilepsy, where neurostimulators detect and counteract seizure activity. Translating this to psychiatry, AI could modulate stimulation intensity based on real-time mood or anxiety biomarkers (e.g., heart rate variability and cortical activity).

CHALLENGES: BEYOND THE HYPE

Despite the enthusiasm, significant hurdles loom large over the application of AI in neuromodulation:

1. Data quality and bias: AI models are only as robust as their training data. Biased datasets (e.g., underrepresenting ethnic minorities or women) risk perpetuating inequities. Recently, it has been reported that 80% of neuroimaging studies are skewed towards Western, educated populations, limiting generalizability.
2. Clinical integration: How will AI tools interface with workflows? Will they augment or disrupt? Training and infrastructure upgrades are essential, yet resource constraints in public health systems may widen disparities in access.
3. Transparency and trust: Many AI algorithms operate as "black boxes," obscuring decision-making. We must demand explainable AI tools that clarify why a patient is deemed a TMS candidate or how a stimulation target was chosen.

ETHICAL IMPERATIVES: NAVIGATING THE UNKNOWN

Ethical dilemmas abound. Patient autonomy, informed consent, and data privacy demand rigorous safeguards. For instance, who owns the neural data collected by implantable devices? Could insurers misuse predictive models to deny coverage? Moreover, overreliance on AI risks eroding the therapeutic alliance, and patients may perceive algorithmic recommendations as impersonal or deterministic. We must champion ethical frameworks that prioritize transparency, equity, and human agency.

THE ROAD AHEAD: COLLABORATION AND CAUTION

The future lies in the integration of AI with digital phenotyping (e.g., smartphone apps tracking sleep or speech patterns) and integration of clinical experiences with those data scientists. Initiatives like the NIH's BRAIN Initiative underscore the value of cross-disciplinary collaboration.[4] Yet, as stewards of patient well-being, psychiatrists must balance innovation with vigilance. Advocate for robust clinical trials, regulatory oversight, and ongoing education to harness AI's potential responsibly.

A TOOL, NOT A PANACEA

AI-enhanced neuromodulation is not a replacement for clinical judgment but a powerful adjunct. It invites us to reimagine psychiatry's future: One where treatments are precisely calibrated to individual neurobiology, where resilience is nurtured through adaptive technologies, and where the art of healing evolves alongside science. As we stand at this crossroads, let us proceed with both ambition and humility–for our patients deserve nothing less.

REFERENCES

1. Cohen SL, Bikson M, Badran BW, George MS. A visual and narrative timeline of US FDA milestones for transcranial magnetic stimulation (TMS) devices. Brain Stimul 2022;15:73-5.
2. Vida RG, Sághy E, Bella R, Kovács S, Erdősi D, Józwiak-Hagymásy J, *et al*. Efficacy of repetitive transcranial magnetic stimulation (rTMS) adjunctive therapy for major depressive disorder (MDD) after two antidepressant treatment failures: meta-analysis of randomized sham-controlled trials. BMC Psychiatry 2023;23:545.
3. Wade B, Barbour T, Ellard K, Camprodon J. Predicting dimensional antidepressant response to repetitive transcranial magnetic stimulation using pretreatment resting-state functional connectivity. Research Square [Preprint]; 2023:rs.3.rs-3204245.
4. Ramos KM, Rommelfanger KS, Greely HT, Koroshetz WJ. Neuroethics and the NIH BRAIN initiative. J Responsible Innov 2018;5:122-30.

How to cite this article: Siddiqui MA, Garg S. Artificial intelligence and neuromodulation: A new frontier in psychiatry. Arch Biol Psychiatry. 2024;2:55-6. doi: 10.25259/ABP_3_2025