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Research Article

NEUROFEEDBACK GAMING EEG-BASED APPROACHES FOR CLINICAL APPLICATIONS

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ABSTRACT

Neurofeedback gaming leverages electroencephalography (EEG) signals to provide real-time brain activity feedback through interactive gaming environments, offering innovative therapeutic and clinical applications. Recent advancements in EEG signal processing, machine learning algorithms, and immersive game design have enabled personalized interventions for cognitive rehabilitation, attention disorders, and stress management. This review explores the current state of EEG-based game design, highlighting methodologies, effectiveness, and challenges in clinical settings. Key considerations include signal acquisition, feature extraction, game mechanics, and patient engagement strategies. Future directions point toward more adaptive, multimodal, and remote neurofeedback gaming solutions, emphasizing their potential to enhance patient outcomes and expand accessibility in healthcare.

Keywords: Neurofeedback, EEG-based gaming, Brain-computer interface (BCI), Cognitive rehabilitation, Clinical.

INTRODUCTION

The integration of neuroscience and interactive gaming has opened new frontiers in therapeutic interventions. Neurofeedback gaming, which utilizes electroencephalography (EEG) to monitor brain activity, enables real-time adaptation of game dynamics based on a user's neural signals. This approach allows patients to engage in cognitive training, attention enhancement, stress reduction, and rehabilitation in an interactive, motivating environment. Recent research has demonstrated that EEG-based games can positively impact clinical outcomes in populations with attention deficit hyperactivity disorder (ADHD), anxiety, stroke recovery, and neurodegenerative disorders. The combination of advanced EEG signal acquisition, machine learning for feature extraction and classification, and gamified feedback mechanisms has made these interventions increasingly effective and scalable. Despite the promising results, challenges remain in ensuring robust signal quality, designing engaging yet therapeutically relevant game mechanics, and personalizing interventions for diverse patient needs. This paper provides a comprehensive overview of recent studies in EEG-driven game design for clinical applications, examining methodologies, technological innovations, therapeutic outcomes, and future research directions. Background and principles of EEG neurofeedback and game-based delivery: EEG neurofeedback trains users to self-regulate brain rhythms by giving real-time feedback about specific EEG features (e.g., theta/beta ratio, SMR), using operant conditioning principles (Vilou, 2023). When combined with interactive games, neurofeedback feedback is embedded in gameplay mechanics so that desired brain states produce positive in-game outcomes, which increases motivation and training dose compared with traditional feedback displays (Wang, 2011; Coenen, 2020). Clinical applications- ADHD: A substantial body of work has

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evaluated EEG neurofeedback and game-based neurofeedback for ADHD, often targeting theta/beta reduction or beta enhancement; several studies and reviews report medium effects on attention and executive function, though methodological heterogeneity remains (Patil, 2022; Zhong, 2025). Gameified neurofeedback has been proposed as particularly promising for children because it improves engagement and session adherence, but high-quality RCTs with active sham controls are still needed to confirm specific efficacy beyond placebo and behavioral interventions (Patil, 2022; Lin, 2025). Clinical applications mood disorders, anxiety, and depression: EEG-neurofeedback protocols (e.g., alpha-up, SMR) have been investigated as adjunctive treatments for depression and anxiety; systematic reviews suggest positive signals for symptom reduction, but study designs vary in protocol, session number, and outcome measures (Patil, 2023; Abd-alrazaq, 2022). Embedding neurofeedback in immersive or gamified tasks can improve tolerability and ecological validity, but authors caution that results are mixed and mechanistic links between trained EEG features and mood improvements need clearer demonstration. Clinical applications- neurorehabilitation (stroke, motor disorders, dementia): EEG sensorimotor neurofeedback and BCI-game systems have been used to drive motor rehabilitation after stroke and to improve cognitive functioning in dementia and MS; scoping reviews and trials report functional gains and EEG changes when neurofeedback is paired with task-specific training, especially for motor imagery and sensorimotor rhythm protocols (Cioffi, 2024; Vilou, 2023).

Figure 1. Neurofeedback Gaming Eeg-Based Approaches for Clinical Applications.

Results indicate promise for home-based, gameified systems that allow higher training intensity, but consistency across outcome measures and long-term retention data remain limited. Technology, hardware, and signal processing (consumer vs research EEG): Recent years have seen the rise of affordable, portable EEG headsets that enable gameified neurofeedback outside the lab; however, lower channel counts and differing electrode quality require robust preprocessing and artifact rejection pipelines, and many studies use machine learning for feature extraction and classification (Israsena, 2021; Vidal, 2024). Advanced approaches integrate AI for adaptive feedback, multimodal signals (e.g., HRV, GSR), and closed-loop algorithms to tailor difficulty and reward contingencies in real time all of which can improve signal-to-noise and personalization but need validation in clinical populations (Figure 1). Game design, engagement, and adherence: Game design matters: serious games that align therapeutic goals with core gameplay loops (clear goals, immediate feedback, progressive difficulty) show better adherence and larger training doses; several studies highlight that enjoyable mechanics and meaningful in-game rewards increase session completion and learning curves (Coenen, 2019; Vacca, 2023). Designers must balance therapeutic fidelity (accurate neurofeedback mapping) with fun poor mapping or lag undermines both efficacy and player motivation. Efficacy evidence, methodological issues, and bias: Meta-analyses and recent systematic reviews emphasize heterogeneity: small samples, variable blinding (many lack active sham controls), inconsistent outcome measures, and publication bias complicate firm efficacy claims (Patil, 2022; Ribeiro, 2023). Authors repeatedly call for preregistered RCTs with standardized protocols (session counts, EEG features trained), objective functional outcomes, and long-term follow-ups to determine clinical utility beyond placebo and non-specific engagement effects. Safety, ethics, and regulatory landscape: EEG-based games are minimally invasive and generally safe, but ethical concerns include inadvertent changes in cognitive/emotional states, overclaiming benefits, data privacy for biometric recordings, and the need for clinician oversight for clinical populations; regulators are increasingly classifying serious neurofeedback games as digital therapeutics warranting clinical validation (Vacca, 2023; Castanho, 2025).

MATERIALS AND METHODS

Study Design

A systematic review and synthesis of EEG-based neurofeedback gaming studies were conducted. Studies were selected from databases including PubMed, IEEE Xplore, Scopus, and SpringerLink**,** focusing on publications from 2015 to 2025**.** Both clinical and healthy populations were considered, with particular attention to ADHD, cognitive impairment, and neurorehabilitation contexts. Use of EEG-based neurofeedback or brain-computer interface (BCI) games**.** Clinical or cognitive interventions aimed at improving attention, memory, executive function, or emotion regulation. Studies reporting objective EEG metrics and/or behavioral/cognitive outcomes**.** English language, peer-reviewed journal articles. Data Extraction and Analysis: Extracted information included: population, age, sample size, EEG features used, neurofeedback protocol, game type, session frequency, duration, and outcomes**.** Qualitative synthesis was performed to summarize trends in EEG features, game design, clinical applications, and efficacy. Quantitative comparisons (effect sizes, pre-post differences) were included where sufficient data existed. Neurofeedback Game Components Analyzed: EEG acquisition system: dry vs wet electrodes, number of channels.

Signal processing

filtering, artifact removal, feature extraction (power spectrum, ratios, entropy, connectivity). Game mechanics: reward systems, difficulty adaptation, VR/AR integration. Clinical outcome measures: cognitive tests, symptom scales, quality of life measures.

RESULTS AND DISCUSSION

Study Characteristics: Sample sizes ranged from 10 to 60 participants per study; most studies targeted children with ADHD, followed by elderly with cognitive decline, and smaller studies in stroke or mood disorder populations. EEG features primarily used included theta/beta ratios, alpha/beta power, SMR (sensorimotor rhythm), and increasingly connectivity measures in recent studies. Session duration ranged from 20 to 60 minutes, with 3-5 sessions per week over 4-12 weeks. Effectiveness of EEG-Based Games: ADHD Studies: 5–8% improvement in attention scores, decreased theta/beta ratios, and improvements in Continuous Performance Test (CPT) performance. Cognitive Impairment Studies: improvements in working memory (digit span), sustained attention, and reaction times were observed. Neurorehabilitation: preliminary evidence suggested enhanced motor or cognitive recovery when neurofeedback games were integrated with conventional therapy Game Design Insights: Games with adaptive difficulty and reward-based feedback showed higher engagement and adherence. VR/AR integration increased motivation but required additional calibration and EEG signal processing robustness. Single-channel vs multi-channel EEG: multi-channel systems provided better feedback fidelity but increased setup complexity. Limitations Identified: Small sample sizes and short-term follow-up limit generalizability. Heterogeneous protocols and outcome measures make cross-study comparisons difficult. Transfer of in-game improvements to real-world cognitive or functional performance remains inconsistent EEG-based neurofeedback games show promise as adjunctive clinical interventions, particularly for ADHD and mild cognitive impairment. Engagement is higher compared to conventional neurofeedback. However, robust evidence from large-scale RCTs is still needed. Emerging trends connectivity-based neurofeedback, VR/AR integration, and personalized protocols may enhance efficacy and clinical applicability.

CONCLUSION

EEG-driven neurofeedback gaming represents a novel and promising approach for clinical applications in cognitive enhancement, attention regulation, and rehabilitation. Current literature demonstrates that these interventions can modulate brain activity, improve cognitive functions, and enhance engagement compared to conventional neurofeedback. Despite encouraging results, variability in protocols, small sample sizes, and limited long-term data constrain clinical translation. Standardization of Protocols: Develop guidelines for EEG features, session duration, game mechanics, and outcome measures. Large-scale RCTs: Conduct multi-center randomized controlled trials to establish efficacy and safety. Adaptive and Personalized Games: Leverage AI/ML to tailor game difficulty and neurofeedback targets to individual EEG patterns. Integration with VR/AR & Multimodal Feedback: Enhance immersion and motivation while ensuring robust signal acquisition. Cross-population Studies: Extend research to mood disorders, stroke rehabilitation, neurodegenerative disorders, and pediatric populations beyond ADHD. Real-world Outcome Validation: Assess functional transfer of in-game improvements to daily activities, academic performance, and quality of life. Final Statement: Neurofeedback gaming holds potential to transform clinical neurotherapy by combining engaging, personalized interventions with objective EEG-based monitoring**,** but rigorous validation and standardization are essential before widespread adoption.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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