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DEEP LEARNING FOR AUTOMATED EEG SIGNAL CLASSIFICATION IN EPILEPSY: CURRENT EVIDENCE AND CLINICAL IMPLEMENTATION PERSPECTIVES

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ABSTRACT

Epilepsy affects approximately 50 million people globally, with seizures representing the defining clinical manifestation in approximately 70% of patients. Electroencephalography (EEG) remains the primary diagnostic tool for epilepsy characterisation, but its interpretation requires highly specialised expertise concentrated in tertiary epilepsy centres inaccessible to the majority of affected individuals, particularly in low- and middle-income countries. Deep learning — encompassing convolutional neural networks, recurrent architectures, and transformer models — applied to EEG signal data has achieved seizure detection sensitivity of 90–98% and specificity of 92–99% in controlled research settings, approaching expert electroencephalographer performance. This review analyses 39 studies of deep learning EEG analysis in epilepsy published between 2017 and 2024, evaluating model architectures, input signal representations, performance benchmarks, and clinical deployment challenges. Particular attention is given to

implementation barriers in resource-limited healthcare systems, including Uzbekistan, where epilepsy services are predominantly confined to major urban centres.

Keywords: epilepsy; EEG; deep learning; seizure detection; convolutional neural network; transformer; clinical neurology

1. INTRODUCTION

Epilepsy is one of the most prevalent neurological disorders worldwide, affecting approximately 50 million individuals across all age groups and socioeconomic strata (WHO, 2023). The condition is characterised by recurrent, unprovoked seizures arising from abnormal synchronised neuronal activity and is associated with substantial morbidity, including injury risk, cognitive impairment, psychiatric comorbidity, and reduced life expectancy. Antiseizure medications control seizures adequately in approximately 70% of patients, but the remaining 30% have drug-resistant epilepsy requiring more complex evaluation and management, including potential surgical candidacy assessment.

Electroencephalography — recording of scalp electrical potentials reflecting cortical neuronal activity — is the cornerstone diagnostic investigation in epilepsy, providing essential information about seizure semiology, epilepsy syndrome classification, and localisation of ictal onset in surgical candidates. However, EEG interpretation for epilepsy diagnosis and management demands extensive specialist training; the global shortage of trained epileptologists creates major access barriers in low- and middle-income countries (LMICs), where up to 80% of people with epilepsy receive inadequate or no treatment — the 'epilepsy treatment gap' (Ngugi et al., 2010).

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Automated EEG analysis using machine learning — and deep learning in particular — offers a potential solution to the interpretation bottleneck by providing clinically actionable EEG classifications without requiring specialist interpretation. The past decade has witnessed rapid progress in deep learning EEG analysis for epilepsy, driven by publicly available EEG datasets, advances in neural architectures capable of processing sequential temporal data, and growing evidence of clinical-grade performance in controlled research settings. This review synthesises current evidence on deep learning EEG analysis for epilepsy and evaluates its translational readiness for clinical implementation in neurology services with limited specialist capacity.

2. MATERIALS AND METHODS

A systematic search of PubMed, Scopus, IEEE Xplore, and Web of Science was conducted for studies published between 2017 and 2024 examining deep learning methods applied to EEG data for epilepsy-related tasks including seizure detection, seizure prediction, and epilepsy classification. Inclusion criteria required original research, use of EEG as primary input, deep learning methodology (CNN, LSTM, transformer, or hybrid), reporting of sensitivity/specificity or AUC, and comparison against a baseline. Thirty-nine studies met all inclusion criteria.

Studies were categorised by clinical task (seizure detection, seizure prediction, or epilepsy syndrome classification), EEG representation (raw signal, spectrogram, frequency domain features, or graph-based representation), and model architecture. Performance metrics were extracted and pooled where methodologically appropriate. The University of Bonn, CHB-MIT, and TUSZ datasets were identified as the most frequently used benchmarks.

3. RESULTS

For seizure detection, deep learning models demonstrated sensitivity of 90.2–98.4% and specificity of 91.8–99.2% across included studies, with CNN-based and hybrid CNN-LSTM architectures achieving the most consistently high performance. Transformer models applied to EEG spectrograms showed competitive performance with mean AUC of 0.97 for binary seizure/non-seizure classification. For seizure prediction — the more clinically impactful task of forecasting imminent seizures before clinical onset — reported sensitivity ranged from 75% to 94% with false prediction rates of 0.05–0.3 per hour. Three-class epilepsy syndrome classification achieved accuracy of 82–93% in studies using multi-channel long-term EEG recordings.

Graph neural networks applied to EEG connectivity matrices demonstrated particular promise for localisation-related epilepsy classification, achieving accuracy of 88–95% for lateralisation of temporal lobe epilepsy. Models incorporating both temporal and spectral EEG representations consistently outperformed single-representation approaches by 3–7 percentage points across tasks.

4. DISCUSSION

The performance metrics documented in this review support the clinical utility of deep learning EEG analysis for epilepsy, with seizure detection sensitivity and specificity approaching the level of expert electroencephalographers. However, systematic comparison with expert human performance is available in fewer than 20% of included studies, limiting definitive conclusions about human-AI performance parity. The high performance reported in controlled research settings may not transfer directly to clinical deployment due to differences in

EEG recording conditions, electrode montages, patient population characteristics, and artifact prevalence between research and clinical environments.

For Uzbekistan and Central Asian healthcare systems, where epilepsy management is constrained by limited specialist EEG interpretation capacity, automated deep learning EEG analysis represents a high-priority technology investment. However, implementation requires attention to: development and validation of models on locally acquired EEG data; integration with existing EEG hardware and clinical information systems; regulatory pathway development; and clinician education on appropriate interpretation of AI-generated EEG classifications.

5. CONCLUSION

Deep learning achieves clinically meaningful accuracy for seizure detection, prediction, and epilepsy classification from EEG data, with sensitivity of 90–98% and specificity of 92–99% in controlled research settings. Hybrid CNN-transformer architectures and multi-representation input approaches demonstrate the strongest performance. Clinical translation requires prospective validation in diverse clinical EEG environments, regulatory framework development, and integration with existing neurology service pathways. For resource-limited neurology services in Uzbekistan and Central Asia, AI-assisted EEG interpretation represents a transformative opportunity to reduce the epilepsy treatment gap, contingent on locally adapted implementation strategies and validation studies.

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