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Perspective

Quantitative EEG Analysis in Early Detection of Alzheimer's Disease

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DESCRIPTION

Alzheimer's Disease (AD) continues to pose one of the most significant public health challenges globally, particularly in aging populations across high-income countries. Despite increasing awareness and advances in imaging and biomarker research, the early detection of AD remains elusive. Clinical symptoms often appear only after substantial neuronal loss has occurred, limiting the effectiveness of therapeutic interventions. Among emerging tools for early diagnosis, Quantitative ElectroEncephaloGraphy (qEEG) is gaining momentum for its potential to detect neurophysiological changes that precede overt cognitive decline. Unlike conventional EEG, which provides qualitative understanding through visual inspection of waveforms, qEEG employs mathematical and statistical algorithms to analyse brain electrical activity across frequency bands and spatial distributions. This allows for objective, reproducible and sensitive assessments of brain function.

In the context of Alzheimer's disease, qEEG offers several unique advantages. Research has consistently demonstrated that AD is associated with specific electrophysiological patterns, such as increased delta and theta activity and reduced alpha and beta power reflecting a shift toward cortical hypoactivity and neuronal disconnection. These changes are measurable even in individuals with mild cognitive impairment (MCI), a prodromal phase of AD, indicating that qEEG can serve as a non-invasive biomarker for early detection. One of the key strengths of qEEG lies in its temporal resolution. Unlike structural imaging techniques like MRI or CT, which detect anatomical changes relatively late in the disease process, qEEG can capture dynamic functional alterations at the millisecond level. This makes it particularly well-suited for identifying early synaptic dysfunction a hallmark of AD pathology. Moreover, qEEG is less costly, more accessible and safer than PET imaging, which requires radioactive tracers and is typically reserved for advanced diagnostic settings.

Several studies have explored the predictive power of qEEG in identifying individuals at high risk of developing Alzheimer's. For instance, longitudinal qEEG analysis has shown that specific spectral and connectivity abnormalities in resting-state EEG are correlated with progression from MCI to AD. Advanced qEEG techniques, including coherence analysis, source localization and machine learning integration, have further improved the specificity and sensitivity of this approach. Particularly potential is the integration of Artificial Intelligence (AI) with qEEG data. Machine learning algorithms trained on large datasets can detect complex patterns and interactions within EEG features that are not easily discernible to the human eye. These models have demonstrated encouraging results in classifying patients with early-stage AD *versus* healthy controls, with some achieving accuracy rates above 85%. This synergy between computational neuroscience and electrophysiology opens new avenues for scalable, real-time screening tools.

Nonetheless, there are several limitations and challenges that must be addressed before qEEG can be adopted widely in clinical practice. Standardization is a major hurdle. Variability in EEG acquisition protocols, electrode placement, artifact removal techniques and analysis parameters can influence results and hinder reproducibility across studies and institutions. International efforts to harmonize qEEG methodologies are critical to ensure clinical utility. Interpretability and clinician training also remain important considerations. While qEEG provides quantitative metrics, their clinical interpretation still requires expert contextualization. Many neurologists are not yet trained in the use of advanced EEG analytics and tools must be designed with user-friendly interfaces that translate complex data into actionable understands.

Moreover, although qEEG shows promise in identifying early AD pathology, it should be viewed as part of a multimodal diagnostic approach. Combining qEEG with neuropsychological assessments, genetic profiling and fluid biomarkers (such as CSF tau or blood-based amyloid markers) may provide the most accurate and comprehensive early detection strategy. From a public health perspective, implementing qEEG screening in primary care or community clinics could help identify at-risk individuals before irreversible damage occurs. This could open the door to earlier lifestyle interventions, clinical trial enrolment and future disease-modifying therapies.

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CONCLUSION

Quantitative EEG represents a compelling, non-invasive and cost-effective tool for the early detection of Alzheimer's disease. By capturing subtle neurophysiological changes associated with synaptic dysfunction, qEEG can identify risk patterns well before the onset of clinical symptoms. Its high temporal resolution, combined with advances in computational analysis, positions it as a valuable asset in the fight against neurodegeneration. However, realizing the full potential of qEEG requires standardized protocols, cross-disciplinary collaboration and integration into broader diagnostic frameworks. With continued research, education and technological refinement, qEEG could transition from research settings to real-world clinical practice offering new hope for early diagnosis and prevention in Alzheimer's disease. As the burden of dementia continues to rise globally, particularly in high-income aging societies, the adoption of innovative, accessible diagnostic tools like qEEG is not just a scientific priority it is a moral imperative.