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NOVA: A Neurofeedback-Optimized Virtual Assistant with Local Large Language Model Integration

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Abstract

As attention-related cognitive disorders affect millions globally, there is a critical need for accessible, human-centric tools to monitor and improve mental well-being. This paper introduces NOVA, a real-time neurofeedback system that integrates electroencephalography (EEG) with local Large Language Models (LLMs) to enhance cognitive focus and relaxation. Addressing the ergonomic challenge of human-computer interaction in digital health, NOVA utilizes the Muse-2 EEG headset to capture brainwave data, which is processed through bandpass filtering (1–30 Hz) and Power Spectral Density (PSD) feature extraction. The system employs a fine-tuned, 2-billion parameter Gemma-2 model running locally to ensure data privacy and a response latency of less than 0.2 seconds, significantly outperforming cloud-based alternatives like GPT-4o. A custom adaptive interface scales difficulty based on the user's real-time focus levels, providing an ergonomic feedback loop. Clinical testing over ten sessions demonstrated substantial increases in focus and relaxation durations, with findings validated by strong correlation ($\rho > 0.9$) and high statistical significance ($p < 0.001$). The fine-tuned local model achieved 97% accuracy in state classification, proving the efficacy of using consumer-grade hardware for high-fidelity cognitive intervention. This research contributes to a scalable, privacy-preserving framework for healthcare informatics and personalized ergonomics, demonstrating how integrated neuro-AI systems can fundamentally improve human performance and system resilience in healthcare environments.

Keywords
Neurofeedback, Local LLM, Healthcare Informatics, Cognitive Performance, Human-Computer Interaction.

Biographies
Leon Le is a student researcher at the Harker School with a primary focus on Operations Research, Physics-Informed Machine Learning, and Systems Optimization. He has been recognized for his contributions to computational engineering, serving as a 1st Place Winner at the Stem4All Silicon Valley Regional Competition and a State Finalist at the California State Science & Engineering Fair. His research interests include the development of high-performance simulation frameworks for deployable structures and the application of mathematical optimization to Large Language Model infrastructure. Beyond his technical research, Leon is the Public Forum Debate Captain for the Harker Varsity Team and a Junior Youth Board Member for OrigamiUSA, where he leads national youth engagement initiatives. He is dedicated to advancing sustainable and mathematically-guaranteed efficiency in complex AI and engineering systems through the integration of formal Operations Research methodologies and advanced computational modeling.