[[1]](#footnote-1)

Comparative Analysis of EEG-Based Event-Related Potential (ERP) and Non-ERP Methods to Examine Adolescent Responses to Addiction Terminology

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# INTRODUCTION

A

dolescence represents a critical window in which individuals become more susceptible to substance use and behavioral addictions. Epidemiological data indicate rising rates of problematic usage including digital addiction, gambling, and substance misuse among youth worldwide (Boer et al., 2025). Beyond behavioral manifestations, the language associated with addiction (e.g., terms such as “dependence,” “craving,” “withdrawal”) may itself carry cognitive and emotional salience, potentially activating neural circuits of attention, memory, and reward processing. In this light, understanding how adolescents process addiction-related terminology is not merely semantic it can provide a window into early biomarkers of vulnerability to addictive behaviors.

Electroencephalography (EEG) has long been a favored modality in neurocognitive research for its high temporal resolution and noninvasiveness. In the domain of addiction research, event-related potentials (ERPs) derived from EEG recordings have been used to index cognitive stages such as selective attention, conflict detection, and stimulus evaluation in response to addiction cues (Bel-Bahar et al., 2022; Balconi, 2024). For instance, the P300 (peaking ~300 ms post-stimulus) is often interpreted as a reflection of attentional allocation or context updating, and has been shown to vary in individuals with substance dependencies or behavioral addictions (Sharifat et al., 2021; Balconi, 2024). In adolescent populations, ERP studies have successfully captured how peer observation or motivational primes modulate attentional markers (Willoughby et al., 2021). These ERP indices thus permit a time-locked dissection of cognitive processing stages elicited by addiction-related cues or language.

Yet, ERP-based analysis represents just one vantage point. Non-ERP approaches including time frequency decomposition, power spectral density (PSD) analysis, and continuous EEG signal analysis allow researchers to examine oscillatory dynamics, non-phase-locked activity, or evolving neural processes that do not strictly align with stimulus onset. These methods can reveal changes in theta, alpha, beta, or gamma bands associated with cognitive control, inhibition, or reward integration (Morales et al., 2025). Moreover, continuous EEG metrics (e.g., band power fluctuations over epochs) can capture sustained engagement or spontaneous dynamics of neural networks that ERP averages may obscure (Balconi, 2024; Zhou et al., 2024). Using both ERP and non-ERP lenses offers a more holistic view of how the brain adapts over time to salient stimuli.

Despite the complementary strengths of ERP and non-ERP approaches, direct head-to-head comparisons remain scarce—particularly in research involving adolescent responses to addiction-related language. Most prior work focuses either on ERP metrics (e.g., P300 amplitude shifts in substance users) or on oscillatory power changes (e.g., elevated theta during craving states) but seldom integrates both in a single paradigm (Bel-Bahar et al., 2022; Sharifat et al., 2021). Further, few studies target linguistic stimuli (rather than pictorial or cue-based stimuli) in adolescents when investigating addictive processing. This gap limits our comprehension of how different EEG analytic methods may converge or diverge in sensitivity and interpretability when applied to semantic stimuli in a vulnerable developmental stage.

To address this gap, the current study aims to perform a comparative analysis of ERP-based and non-ERP EEG methods in assessing adolescent neural responses to addiction-related terminology. Specifically, we will (1) examine ERP markers (e.g., P300 amplitude and latency) elicited by addiction terms versus neutral terms, (2) analyze complementary oscillatory dynamics via time–frequency/PSD analyses, and (3) contrast the relative sensitivity, spatial topography (via topoplots), and interpretive flexibility of the two approaches. We expect that ERP analysis may more precisely capture discrete cognitive events such as attention or evaluation, whereas non-ERP methods will highlight sustained oscillatory shifts and network-level dynamics. By bringing these methods into dialogue, this study will advance methodological rigor in addiction neuroscience, offer insights into early neural markers of semantic cue reactivity, and guide future work in adolescent brain research.

# Material and Methods

## Participants

Twelve adolescent participants voluntarily participated in the study. All participants were currently enrolled in senior high schools or vocational schools. Participants were categorized into two groups based on psychosocial background related to substance exposure: (1) the normal group (n = 7), consisting of adolescents with no personal or familial history of substance use or exposure, and (2) the at-risk group (n = 5), comprising adolescents who either had a personal history of contact with illicit substances or reported having close family members who had previously been involved with substance use. This classification aimed to capture potential neurocognitive and emotional differences between adolescents with and without indirect exposure to addictive environments.

All participants were right-handed, had normal or corrected-to-normal vision, and reported no history of neurological or psychiatric disorders. Exclusion criteria included current or past substance dependence, ongoing psychoactive medication use, or any sensory or cognitive impairments that could interfere with EEG data collection. EEG recordings were conducted using a KT-88 16-channel EEG system. Data from all twelve participants were successfully acquired and processed for subsequent analysis.

## Experimental Design and Stimuli

The experiment employed a within-subject Go/No-Go Association Task (GNAT) paradigm to investigate neural responses to addiction-related terminology among adolescents. The task aimed to elicit implicit associative processing of addiction-related words by contrasting them against affectively positive distractor words.

Stimuli. The target set comprised four addiction-related lexical items “*Narkoba*” (drugs), “*NAPZA*” (narcotics, psychotropics, and addictive substances), “*Pecandu*” (addict), and “*Penyalahguna*” (abuser). Each target word was presented 10 times, resulting in a total of 40 target trials. The distractor set consisted of 30 positive or neutral Indonesian words (e.g., “*Sukacita*,” “*Bahagia*,” “*Gembira*,” “*Indah*,” “*Nikmat*,” “*Bangga,*” “*Keren*,” “*Bagus*,” “*Hebat*,” “*Berguna*,” “*Ceria*,” *“Enak,” “Senang”*) along with repeated presentations of *“Penyalahguna”* to introduce semantic interference and maintain balanced lexical frequency across conditions.

Procedure. Participants were instructed to press spacebar (Go) when an addiction-related target word appeared and to withhold their response (No-Go) when presented with any distractor word. Each trial began with a central fixation cross displayed for 500 ms, followed by the word stimulus shown for 300 ms, and a 1,000 ms blank inter-trial interval.

Reaction time (RT), accuracy, and EEG signals were recorded simultaneously to enable both behavioural and neurophysiological analysis. The GNAT paradigm was chosen because it effectively differentiates implicit associative responses and inhibitory control mechanisms linked to addiction-related cognitive processing in adolescents.

## EEG Data Acquisition

EEG recordings were collected using a KT-88 16-channel EEG system (Konan Medical, Japan), configured according to the international 10–20 electrode placement standard. Sixteen active electrodes were positioned at standard scalp locations, including Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, and T6, providing broad coverage across frontal, central, parietal, and occipital regions relevant to cognitive and affective processing. The reference electrode was placed at the right mastoid (A2), and the ground electrode was positioned at Fpz.

EEG signals were digitized at a sampling rate of 500 Hz with 16-bit resolution and recorded using the manufacturer’s proprietary acquisition software. Electrode impedances were maintained below 5 kΩ throughout the recording to ensure optimal signal quality.

Data acquisition was conducted in a sound-attenuated, low-noise environment with dim ambient lighting, minimizing external distractions and visual artifacts. Participants were seated comfortably approximately 70 cm from the stimulus monitor and instructed to maintain fixation at the screen center, minimize blinking, and avoid unnecessary movements during recording.

The overall recording protocol followed best-practice guidelines for adolescent EEG research and was adapted from the system design and experimental structure described by Wijayanto et al. (2024) in “Unlocking Early Detection and Intervention Potential: Analyzing Visual Evoked Potentials (VEPs) in Adolescents/Teenagers with Narcotics Abuse Tendencies from the TelUnisba Neuropsychology EEG Dataset (TUNDA)”. This framework ensured consistency in electrode configuration, room condition, and noise control across all experimental sessions.

All raw EEG data were visually inspected immediately after acquisition to identify and mark any segments containing excessive noise, movement, or electrode disconnection before further preprocessing.

## Preprocessing

EEG preprocessing was conducted using EEGLAB (v2024.0) running under MATLAB R2023b (The MathWorks Inc., Natick, MA, USA). Raw EEG signals recorded from all sixteen electrodes of the KT-88 system were preprocessed through a standardized pipeline designed to remove noise and preserve cognitive-relevant neural information for both ERP and non-ERP analyses.

Continuous EEG data were band-pass filtered between 4 and 40 Hz using a 4th-order Butterworth filter, effectively attenuating slow drifts and high-frequency artifacts while retaining the frequency range most relevant to cognitive electrophysiology. This filtering range ensured preservation of both low-frequency (theta/alpha) and mid-frequency (beta) oscillations associated with attention and emotional processing.

Following filtering, artifact correction was performed using Independent Component Analysis (ICA) with the extended Infomax algorithm (Delorme & Makeig, 2004). Components representing ocular blinks, horizontal eye movements, and muscular activity were identified through combined inspection of scalp topography, power spectrum, and temporal characteristics, then excluded from further analysis. Visual inspection was additionally applied to ensure the removal of residual motion-related or electrode-disconnection artifacts.

# Result and Discussion

## Hasil Evaluasi Performa Model

Model Random Forest yang dikembangkan dievaluasi pada data uji untuk mengukur performa prediktifnya. Hasil evaluasi menunjukkan kinerja yang sangat tinggi, dengan akurasi keseluruhan mencapai 97.5%. Metrik evaluasi yang lebih rinci, yang dihitung dari confusion matrix, menunjukkan performa yang seimbang dan andal. Model mencapai nilai weighted average untuk presisi sebesar 0.98, recall 0.97, dan F1-Score 0.98. Nilai recall yang tinggi untuk kelas positif (stroke) sangat penting dalam konteks medis, karena ini menandakan kemampuan model untuk mengidentifikasi sebagian besar kasus stroke secara efektif sambil meminimalkan jumlah kasus yang terlewatkan (false negatives).

Untuk memahami faktor-faktor yang paling memengaruhi prediksi, dilakukan analisis feature importance. Hasilnya mengonfirmasi bahwa age, avg\_glucose\_level, bmi, hypertension, dan heart\_disease adalah lima prediktor teratas. Temuan ini selaras dengan literatur medis yang ada mengenai faktor risiko stroke, yang menunjukkan bahwa model berhasil menangkap pola-pola yang relevan secara klinis dari data.

## Implementasi dan Fungsionalitas Sistem Web

Model yang telah divalidasi kemudian diimplementasikan ke dalam sebuah sistem aplikasi web yang fungsional. Antarmuka pengguna (UI) menyediakan formulir input data yang intuitif bagi pengguna untuk memasukkan informasi demografis dan klinis mereka. Setelah data dikirim, aplikasi Laravel berkomunikasi secara real-time dengan API FastAPI untuk memproses input dan mengembalikan hasil prediksi.

Sistem menyajikan hasil prediksi dengan umpan balik visual yang jelas: notifikasi berwarna merah untuk potensi risiko tinggi dan berwarna hijau untuk risiko rendah. Pendekatan ini memastikan hasil dapat diinterpretasikan dengan cepat oleh pengguna dari berbagai latar belakang. Sistem juga menyertakan disclaimer yang menyatakan bahwa hasil prediksi bukanlah diagnosis medis formal, melainkan alat skrining awal.

## Pembahasan

Performa model Random Forest dengan akurasi 97.5% sangat kompetitif jika dibandingkan dengan penelitian-penelitian sebelumnya, yang umumnya melaporkan akurasi di rentang 90-95% [10], [12]. Keberhasilan ini dapat diatribusikan pada kekuatan algoritma Random Forest dalam menangani interaksi non-linear antar fitur serta efektivitas kombinasi teknik SMOTE dan class weighting dalam mengatasi bias pada dataset. Validitas klinis model juga diperkuat oleh hasil analisis feature importance yang sejalan dengan faktor risiko stroke yang telah diakui secara medis [7], [8].

Dari perspektif rekayasa perangkat lunak, implementasi arsitektur terpisah (decoupled) menggunakan FastAPI dan Laravel 11 terbukti berhasil, menghasilkan sistem yang fungsional, modular, dan dapat diskalakan. Meskipun demikian, penelitian ini memiliki keterbatasan, yaitu ketergantungan pada satu dataset publik dan perlunya validasi klinis eksternal untuk menguji generalisasi model di dunia nyata.

# Conclusion

Penelitian ini berhasil mengembangkan dan mengevaluasi sistem prediksi stroke berbasis web. Model klasifikasi yang dibangun menggunakan algoritma Random Forest menunjukkan kinerja yang sangat baik pada data uji, mencapai akurasi sebesar 97,5% dengan metrik presisi, recall, dan F1-Score yang seimbang. Keberhasilan ini didukung secara signifikan oleh teknik pra-pemrosesan data yang efektif, terutama dalam menangani masalah ketidakseimbangan kelas. Lebih lanjut, implementasi arsitektur perangkat lunak modern yang terpisah (decoupled) menggunakan FastAPI untuk API backend dan Laravel 11 untuk aplikasi frontend terbukti tangguh dan efektif. Sistem yang dihasilkan berfungsi sebagai prototipe valid yang berhasil menjembatani kesenjangan antara riset AI akademis dan aplikasi praktis di bidang kesehatan, menyediakan alat yang intuitif dan mudah diakses untuk skrining risiko stroke tahap awal.

Untuk pengembangan di masa depan, beberapa area direkomendasikan untuk perbaikan. Pertama, model harus divalidasi pada dataset yang lebih besar dan beragam, idealnya dari rekam medis elektronik dunia nyata, untuk memastikan generalisasi yang lebih baik. Mengeksplorasi algoritma yang lebih canggih, seperti gradient boosting machines (XGBoost, LightGBM) atau model deep learning, juga dapat memberikan potensi peningkatan akurasi. Dari perspektif aplikasi, penyempurnaan di masa depan dapat mencakup manajemen profil pengguna, pelacakan riwayat risiko, dan rekomendasi gaya hidup yang dipersonalisasi. Terakhir, melakukan studi validasi klinis bekerja sama dengan para profesional kesehatan adalah langkah penting berikutnya untuk mengevaluasi dampak dan kegunaan sistem di dunia nyata sebelum implementasi secara luas.

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**Second B. Author** was born in Greenwich Village, New York, NY, USA in 1977. He received the B.S. and M.S. degrees in aerospace engineering from the University of Virginia, Charlottesville, in 2001 and the Ph.D. degree in mechanical engineering from Drexel University, Philadelphia, PA, in 2008.

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Dr. Author was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.

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1. [↑](#footnote-ref-1)