Prediction of Stress-Induced Substance Use via a Multimodal Data Acquisition Framework and an Ensemble Machine Learning Model

Bijoy Chhetri, Lalit Mohan Goyal, & Mamta Mittal

Published in BRAIN: Broad Research in Artificial Intelligence and Neuroscience
Volume 17, Issue 2, 2026

THE RELAPSE BLINDSPOT: FRAGMENTED OBSERVATION

Stress is not merely a consequence of addiction; it is the primary catalyst for initiation, maintenance, and relapse.

CLASSICAL APPROACHES

Self-Reporting Only: Subjective, delayed, prone to bias.

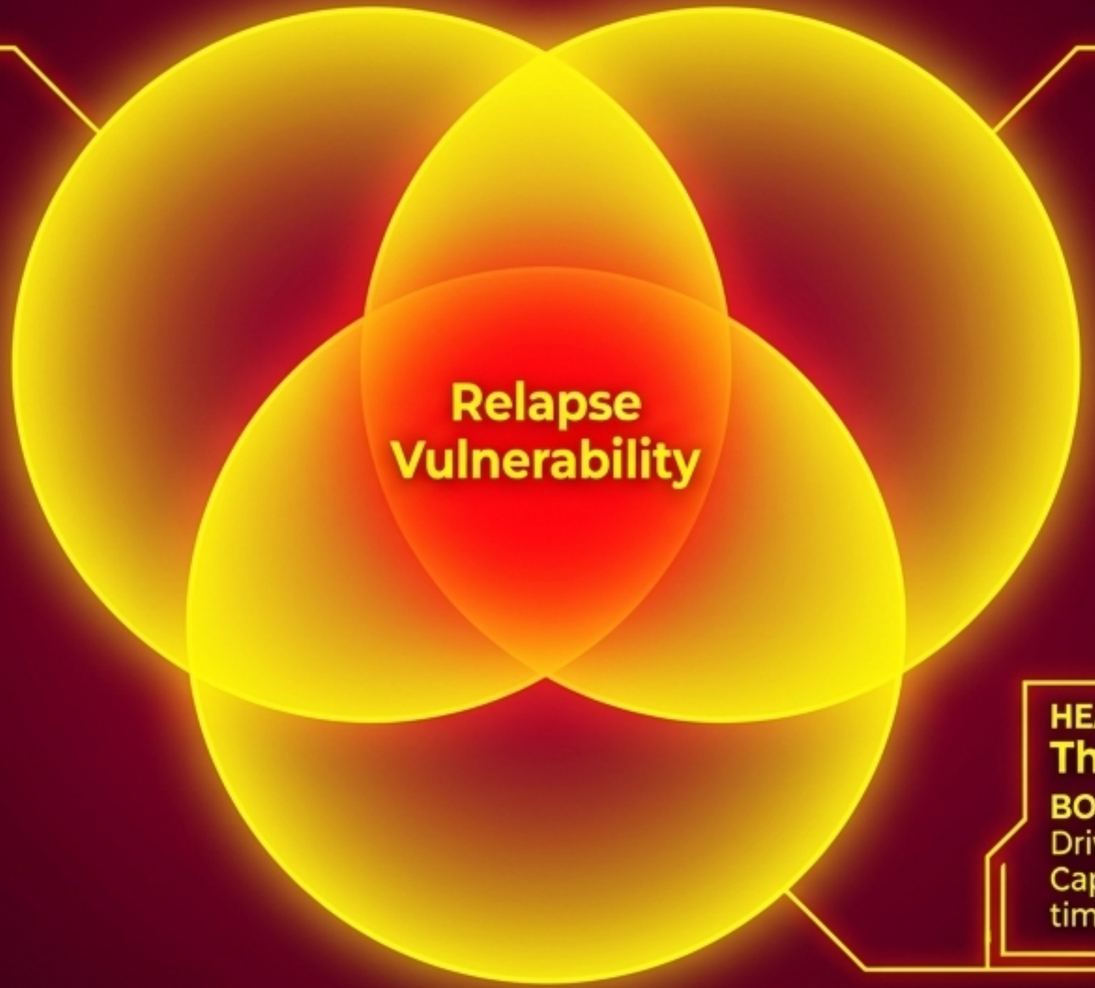
Physiological Only: Lacks cognitive and contextual understanding.

THE REALITY

Traditional methods fail to capture the complex, real-time dynamics between a patient's bodily arousal and their psychological vulnerability in recovery environments.

The Triad of Vulnerability

HEADLINE
The Body (Physiological)
BODY TEXT
Driven by the Sympathetic-Adreno-Medullary (SAM) system. Captured via Wearable ESP32 Sensors (Heart Rate, Galvanic Skin Response, Skin Temperature).

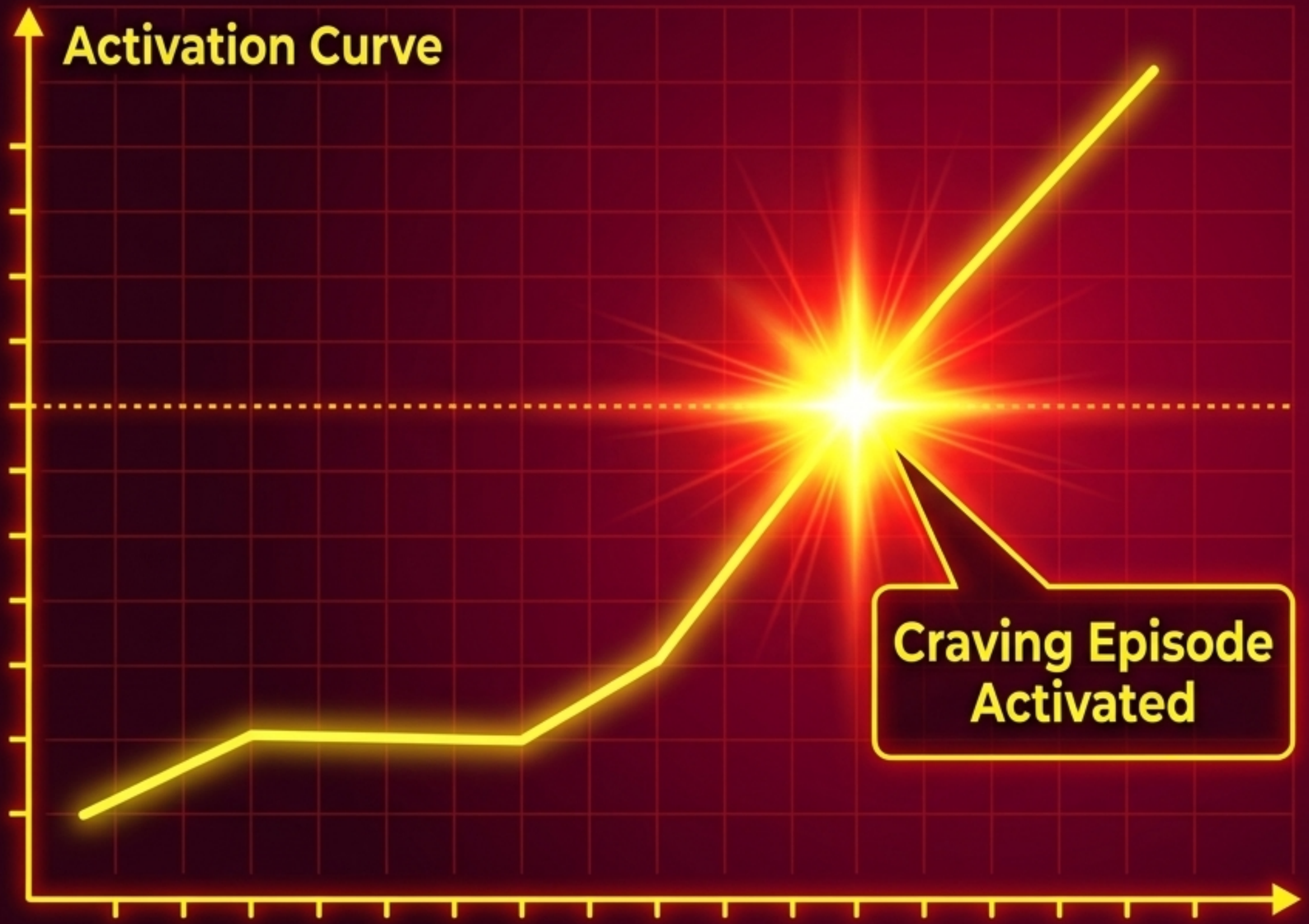


HEADLINE
The Mind (Psychological)
BODY TEXT
Driven by the Hypothalamic-Pituitary-Adrenal (HPA) axis. Captured via the Perceived Stress Scale (PSS) assessment.

HEADLINE
The Urge (Behavioral)
BODY TEXT
Driven by the dopaminergic reward system. Captured via contextual clinical stage and real-time craving intensity scoring.

Takeaway: True prediction only exists at the nexus of physiological hyperarousal, cognitive stress appraisal, and behavioral substance-seeking.

The 70% Nexus: The Stress-Craving Threshold



70% of craving instances **co-occur with elevated stress levels** within a defined temporal window.

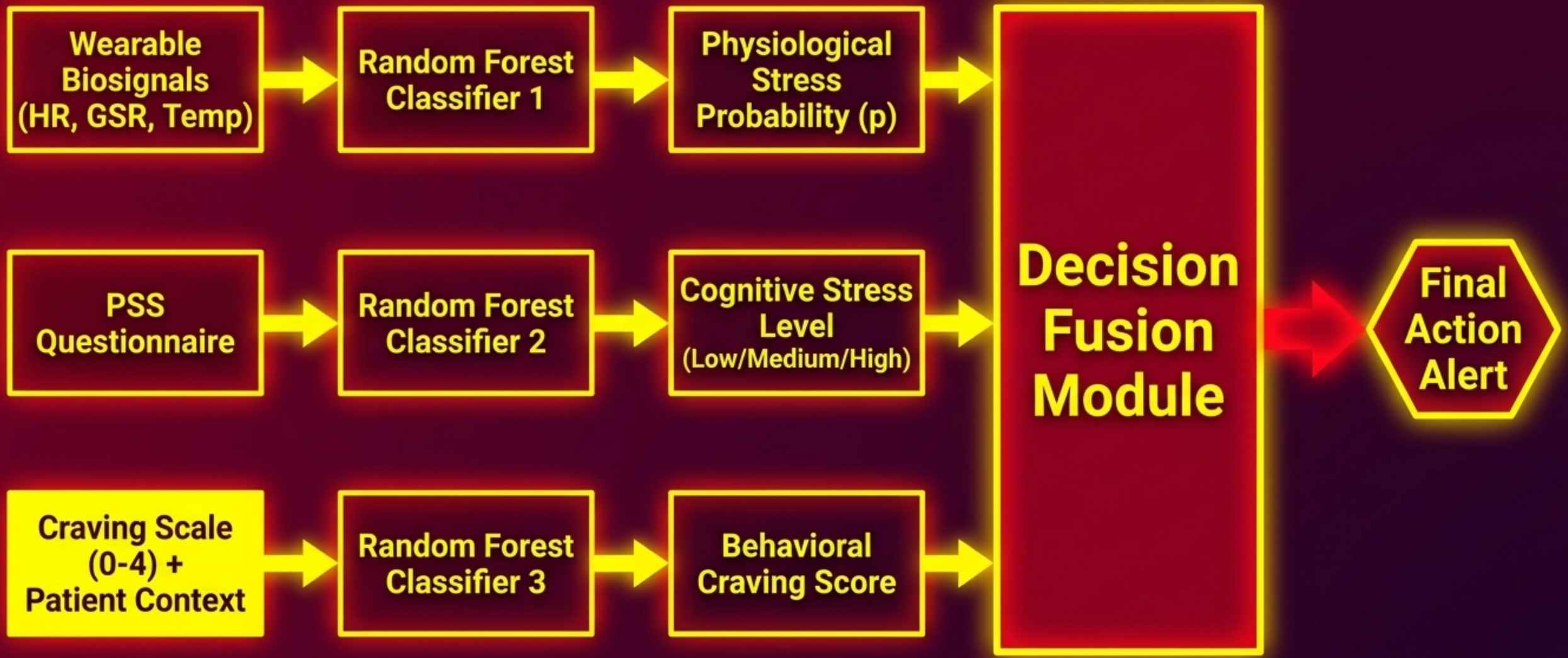
Mind / Craving Link

Correlation (r = 0.73) between psychological stress and craving intensity.

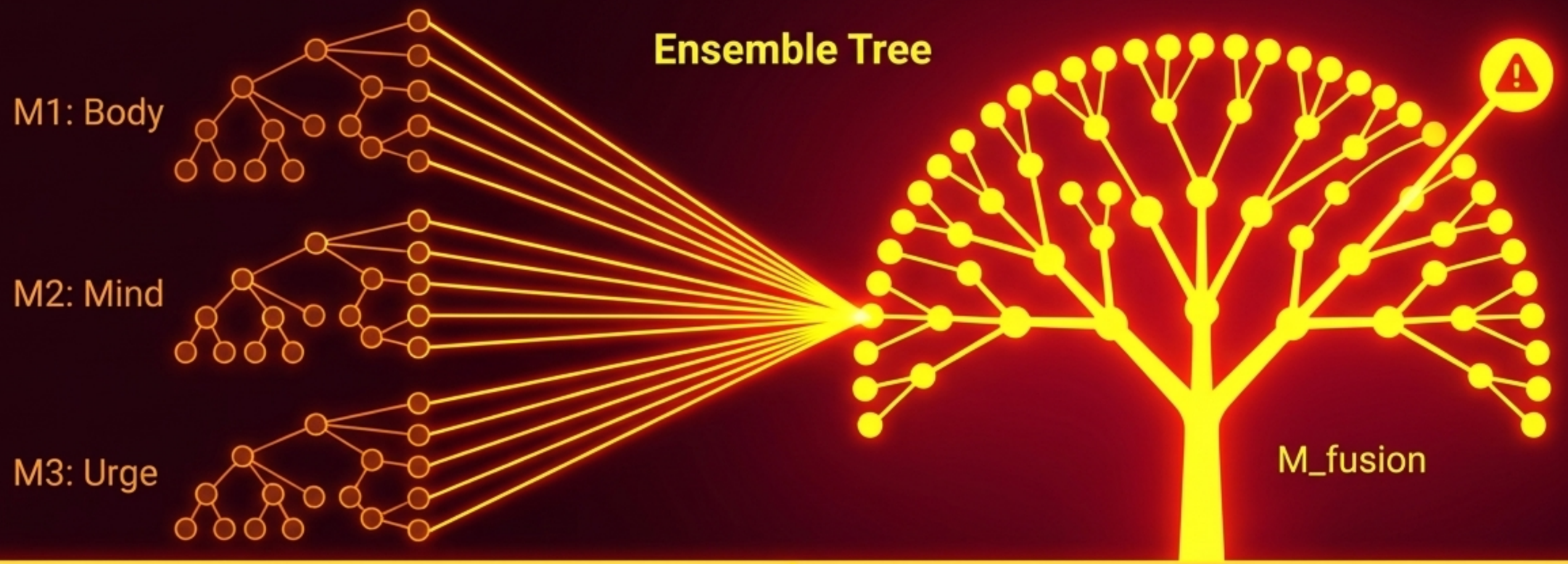
Body / Craving Link

Physiological imbalances (Heart Rate & Electrodermal Activity) mirror this correlation (r = 0.60).

Multimodal Fusion: The Data-to-Decision Pipeline

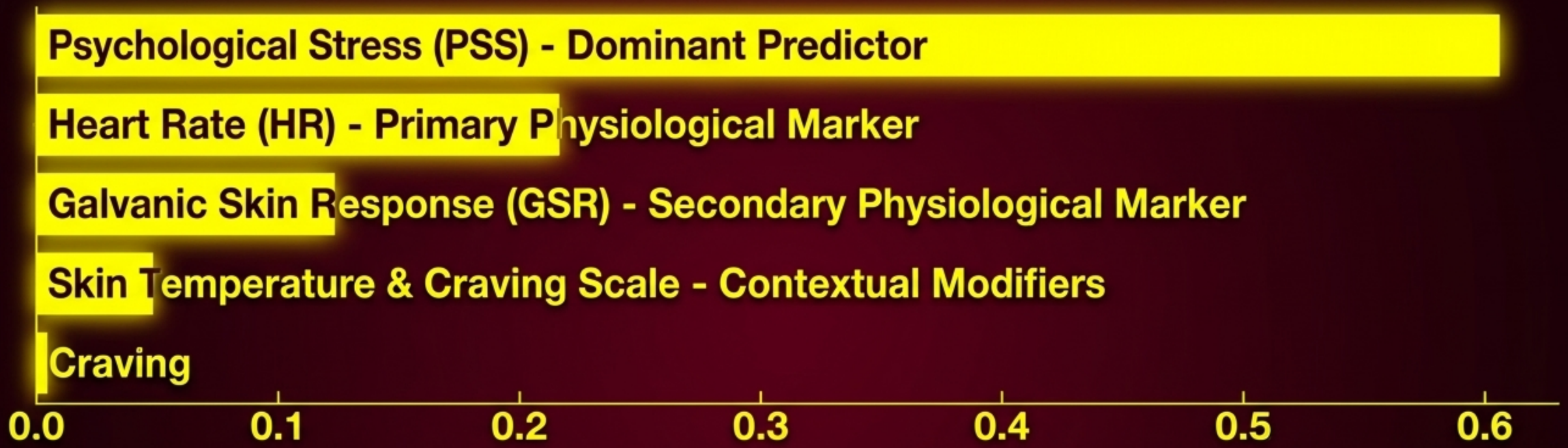


The ERFML Engine: Hierarchical Meta-Classification



Step 1: First-Level Learners	Step 2: The Meta-Classifier
Instead of treating all features uniformly, the system deploys dedicated domain-specific models to independently evaluate the body, the mind, and the urge.	The base model outputs form a new, unified feature vector. The final Fusion Random Forest learns the complex interactions between these modalities, not just raw data correlations. This hierarchical structure isolates signal noise and identifies complex, multi-system triggers.

Decoding the Trigger: Feature Explainability



The Insight:
SHAP analysis definitively proves that while wearable biometrics (HR/GSR) are crucial, the subjective psychological perception of stress remains the most influential factor in predicting relapse vulnerability. Wearables alone are not enough.

The Predictive Edge: Model Comparison Matrix

Model Type	Handles Physiological?	Handles Psychological?	Handles Behavioral?	Final Accuracy
K-Nearest Neighbors (KNN)	✓	○	○	88%
Support Vector Machine (SVM)	✓	○	○	91%
Neural Network (NN)	✓	○	○	92%
Standard Random Forest	✓	○	○	94%
Proposed Fusion ERFML	✓	✓	✓	95% (AUC 0.95)

From Prediction to Protection: The Clinical Action Gauge

Level A4 (Critical Attention)

Concurrent high stress / Imminent relapse risk.
Action: Automated escalation to clinical staff; immediate supervision and possible pharmacological support.

Level A3 (High Attention)

Significant stress / Strong craving.
Action: Structured Cognitive Behavioral Therapy (CBT) exercises and targeted counseling.

Level A2 (Moderate Attention)

Emerging behavioral risk / Moderate stress.
Action: Brief intervention (SBIRT) and stress management training.

Level A1 (Basic Attention)

Elevated stress / Minimal urge.
Action: App initiates automated breathing, mindfulness prompts, and routine monitoring.

A New Paradigm for Addiction Recovery

Card 1

Beyond the Snapshot

Moves addiction treatment away from delayed, subjective self-reporting into continuous, real-time context monitoring.

Card 2

The Power of Synthesis

Achieves **95% predictive accuracy** by recognizing that relapse is an integrated failure of body, mind, and behavior.

Card 3

Proactive Guardianship

Translates invisible biological and psychological triggers into immediate, automated clinical interventions—stopping relapse before the substance is ever consumed.