

MACHINE LEARNING REVEALS NEURAL SIGNATURES OF FEAR IN A RAT MODEL SIMULATING PTSD

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BACKGROUND

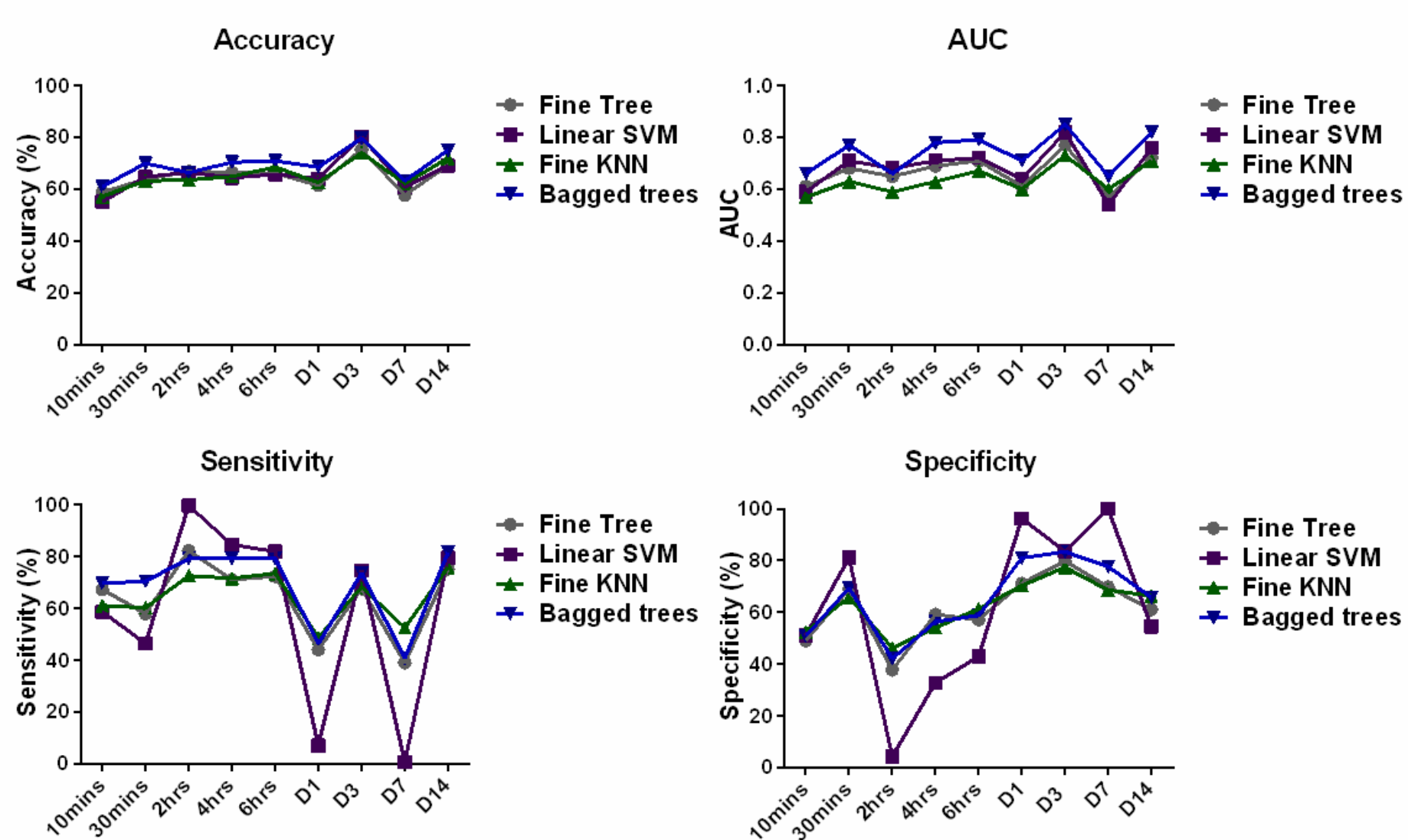
- PTSD Prevalence:** Affects ~3.5% of the U.S. population annually, with lifetime prevalence reaching up to 26.9% in veterans.
- Neural Circuitry:** The amygdala (AMY), medial prefrontal cortex (mPFC), and ventral hippocampus (vHipp) constitute the core fear network regulating PTSD pathophysiology.
- Electrophysiological Biomarker:** Theta-band (4 Hz) local field potential (LFP) oscillations correlate strongly with fear expression and freezing behavior.
- Behavioral Phenotyping Gap:** Pathological freezing and normal immobility are visually indistinguishable via video analysis, necessitating internal physiological differentiation.
- Machine Learning Approach:** Advanced ML algorithms can decode multidimensional neural features to automate, detect, and predict traumatic stress-related fear states.

OBJECTIVES

- Detect freezing behavior.
- Discriminate freezing from immobility.
- Predict freezing occurrence.

RESULTS

1 Detection of Freezing Behavior-AMY



KEY FINDING

Bagged Trees achieved the best overall performance across all brain regions. AMY showed the highest predictive power, reaching AUC 0.61–0.82, peaking at Day 14 (AUC = 0.72).

METHODS

01 Animal Model (Single-Prolonged Stress and Footshock, SPS & FS)

- Male SD rats (N = 5/group)
- Restraint (2 hr) → Forced Swim (20 min) → Ether Exposure → Footshock (1.5 mA × 10 paired with 80 dB CS tone)

02 LFP Recording

Bilateral implantation:

- mPFC
- Amygdala (AMY)
- Ventral Hippocampus (vHipp)

Timepoints:

- Early: 10 min, 30 min, 2 hr, 4 hr, 6 hr
- Late: Day 1, 3, 7, 14

03 Feature Extraction

- FFT → 99 frequency bands (0.5–49.5 Hz)
- 31 extracted features:**
 - Band magnitude
 - Total power
 - Band ratios
 - Hemispheric asymmetry

04 Machine Learning

Algorithms:

- Fine Tree
- Linear SVM
- Fine kNN
- Bagged Trees

Validation: 5-fold Cross Validation

Metrics: AUC, Accuracy, Sensitivity, Specificity

ANALYSIS FRAMEWORK

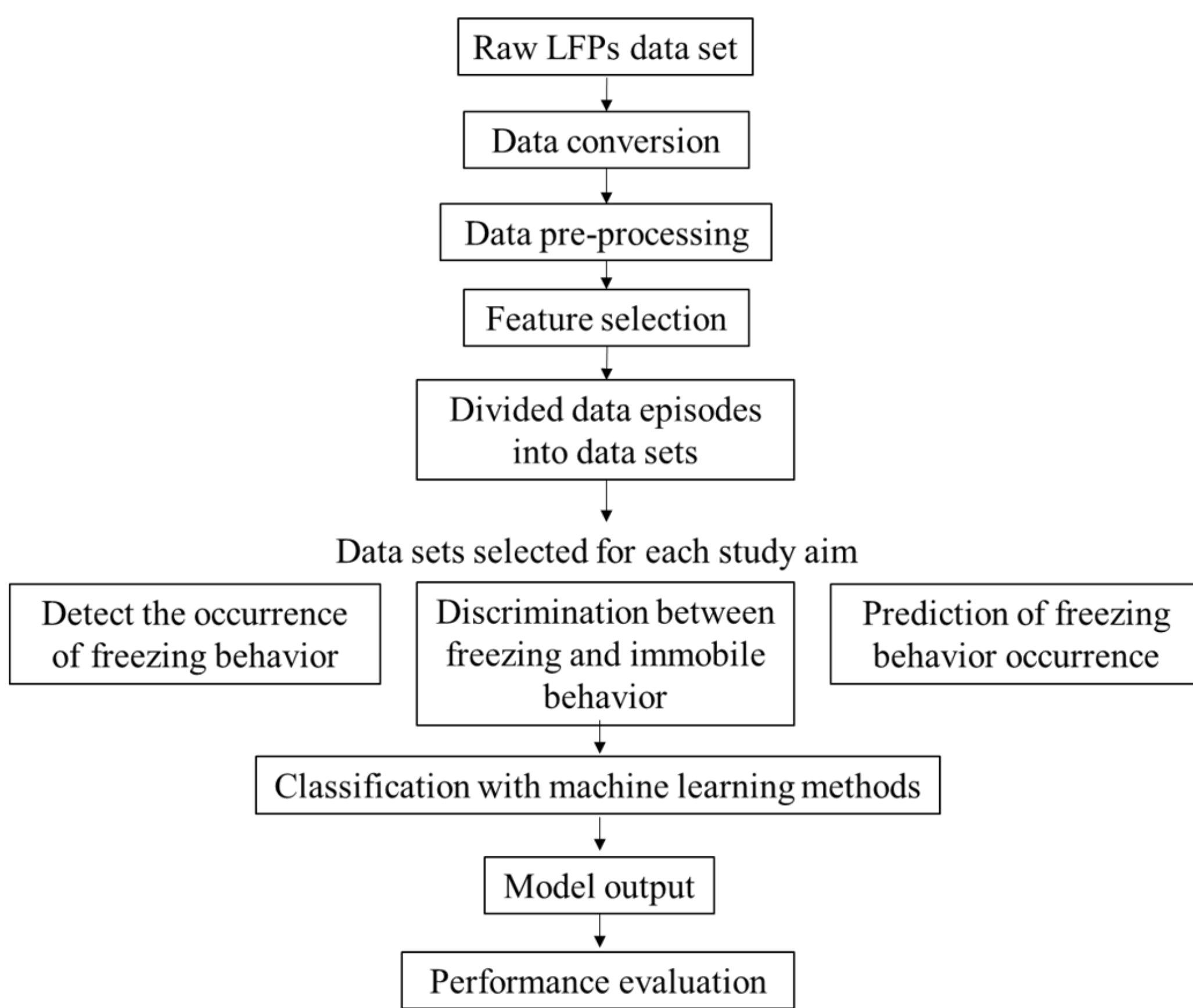


Figure 1. ML pipeline: feature extraction → classification → validation.

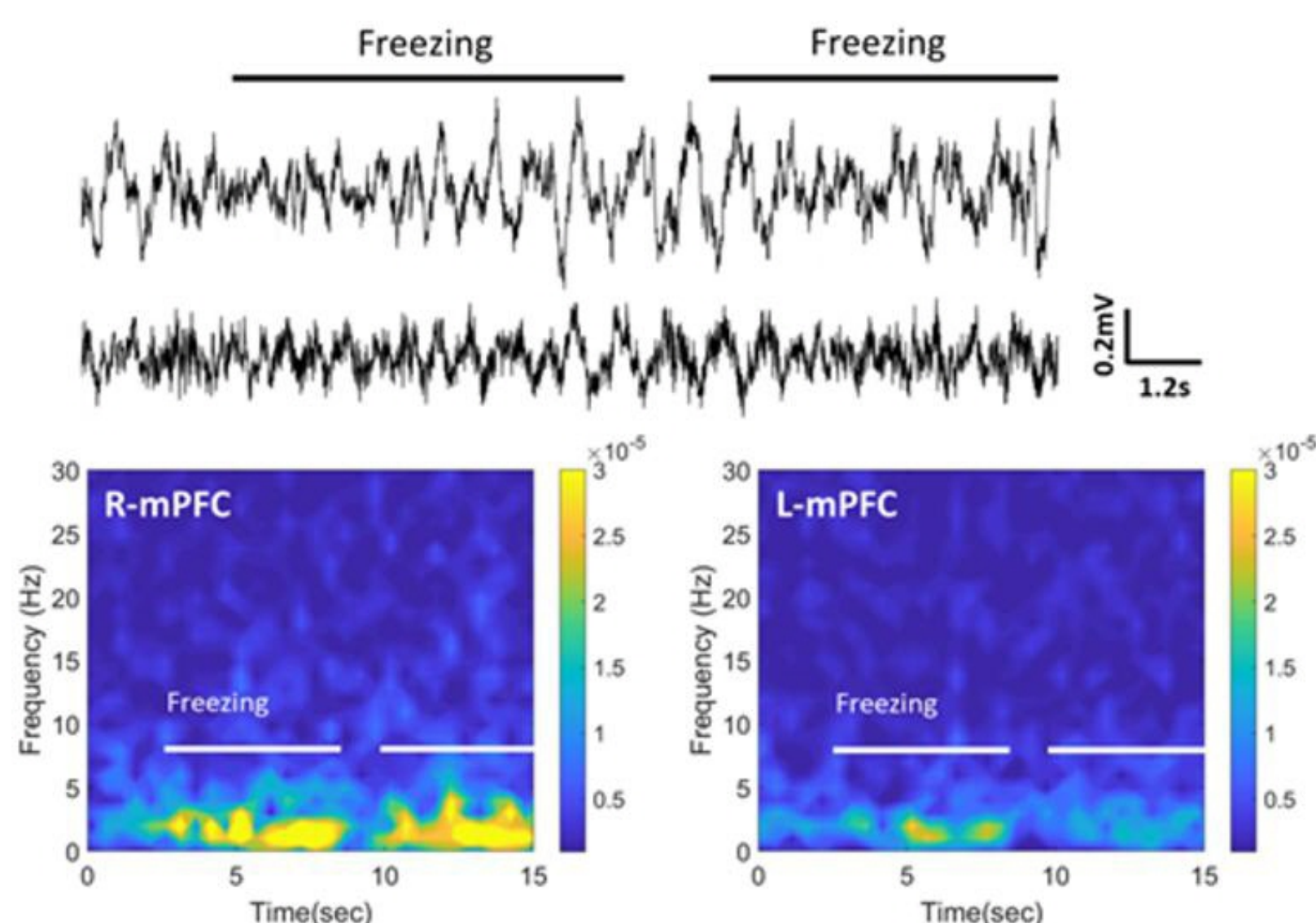


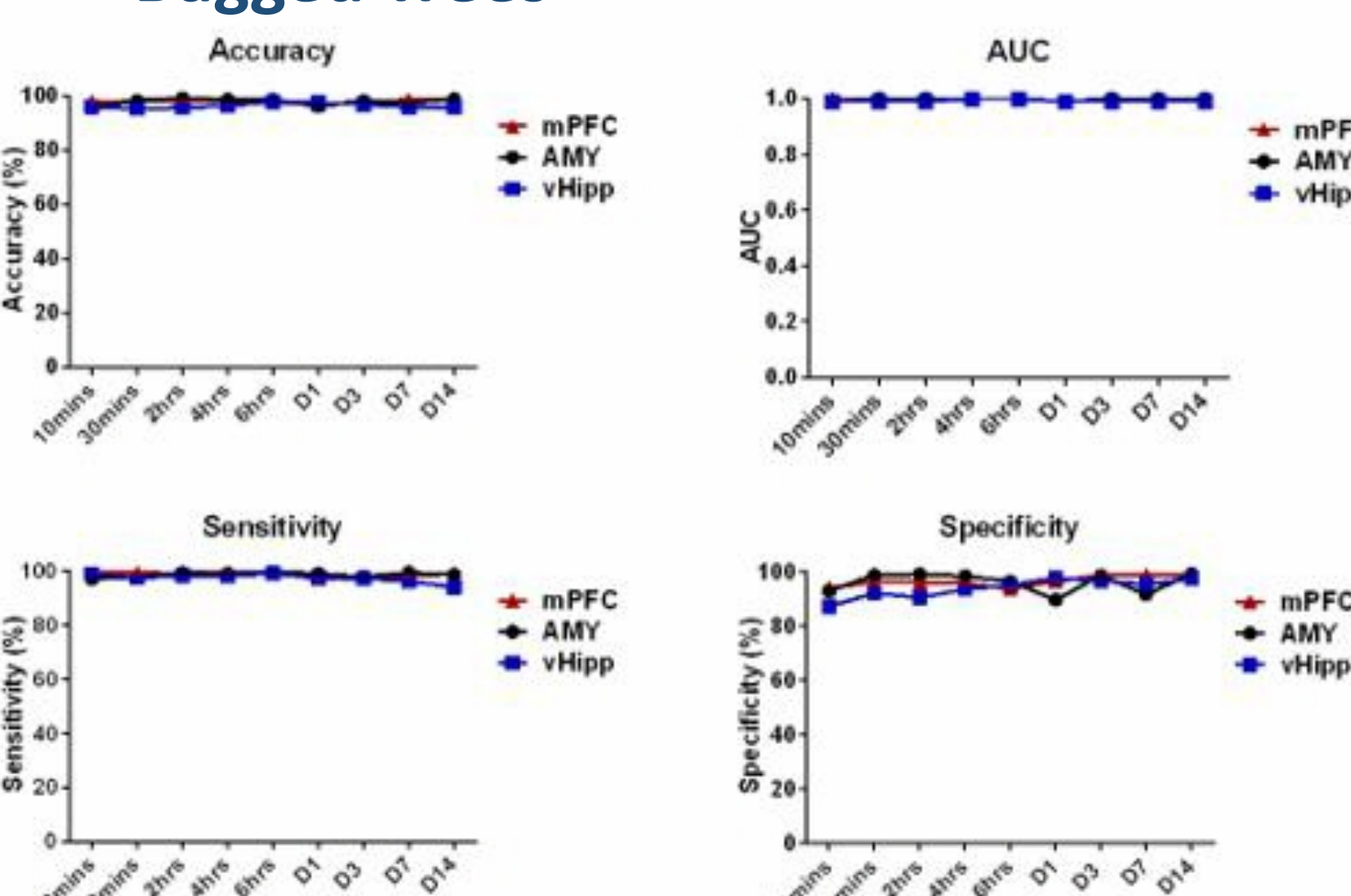
Figure 2. LFPs recorded from the mPFC.

mPFC Executive control and fear regulation

AMY Fear processing hub

vHipp Contextual fear memory

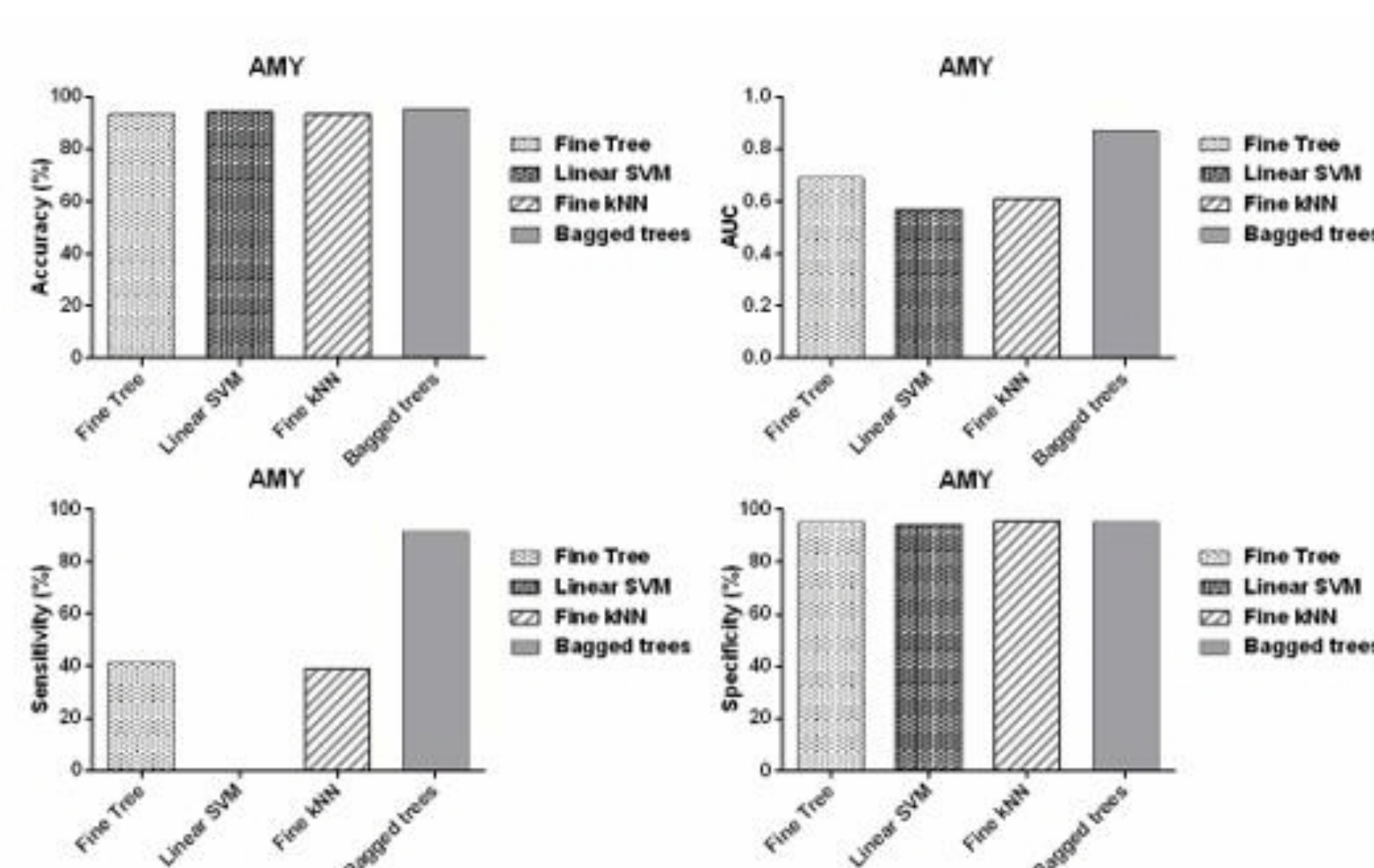
2 Discrimination: Freezing vs. Immobility -Bagged Trees



KEY FINDING

All ML methods achieved >93% classification accuracy. Bagged Trees consistently reached AUC approaching 1.0. Freezing and immobility show fundamentally distinct neural signatures.

3 Prediction of Freezing Occurrence-AMY



KEY FINDING

Bagged Trees coupled with AMY signals yielded the highest performance, achieving 95.4% accuracy, 0.87 AUC, and 91.46% sensitivity.

CONCLUSION

- AMY demonstrated superior predictive capacity compared to mPFC and vHipp.
- Successful early prediction of freezing epochs, Bagged Trees outperformed Fine Tree, SVM, and kNN.
- Future Work: Human EEG translation.

PREDICTION PERFORMANCE

Region	AUC	Sensitivity
AMY	0.87	91.46%
mPFC	0.59	18.18%
vHipp	0.58	14.29%