AI-enabled Narcolepsy Type-1 Screening with PPG: a Proof-of-Concept Study

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Introduction

While highly specific, the current diagnostic paradigm for type 1 narcolepsy (NT1), defined largely by sleep onset REM period event (SOREMP) observations in PSGs and MSLTs, remains limited by its NT1 disorder sensitivity and procedural complexity. ML methods have shown promise to accurately detect NT1 from PSG-EEG via computational biomarkers. Photoplethysmography (PPG), used for home sleep apnea testing, can determine sleep stages through machine learning without EEG. We explore whether such PPG-based sleep stages are robust enough to detect sleep architectural abnormalities specifically associated with NT1.

Methodology

The dataset included a total of N=110 patients, N=35 positive NT1 patients and N=75 negative NT1 subjects. The negative NT1 patients were composed of N=61 confounding hypersomnolence disorders and N=14 negative controls. We evaluated four separate input data types, trained with stratified 10-fold cross-validation with supervised random forest machine learning (ML) models for NT1 detection. The following four input data types are features derived from two ML models for automated sleep staging with EEG and with PPG signals: PSG EEG-based sleep stage report indices (EEG-Stage), PSG PPG-based sleep stage report indices (PPG-Stage), PSG EEG-based hypnodensity derived features (EEG-Hypno), and PSG PPG-based hypnodensity derived features (PPG-Hypno). To measure performance, we calculated the area under the receiver operating characteristic curve (ROC-AUC) for each model and performed a feature importance analysis for the Sleep-RF model.

Results

ROC-AUC values were 0.894 and 0.852 for the EEG-Hypno and PPG-Hypno models, respectively. Furthermore, ROC-AUC values were 0.794 and 0.798 for the EEG-Stage and PPG-Stage models. The feature importance analysis for the EEG-Stage model revealed these most important features: sleep latency, total N3 time, N3 prevalence, total sleep time, and REM latency. The feature importance analysis for the PPG-Stage model revealed these most important features: sleep latency, REM latency, total N3 time, and N3 prevalence.

PPG vs. EEG-based NT1 detectino performance comparison

ROC curves for PPG-Hypno, EEG-Hypno, PPG-Report, EEG-Report

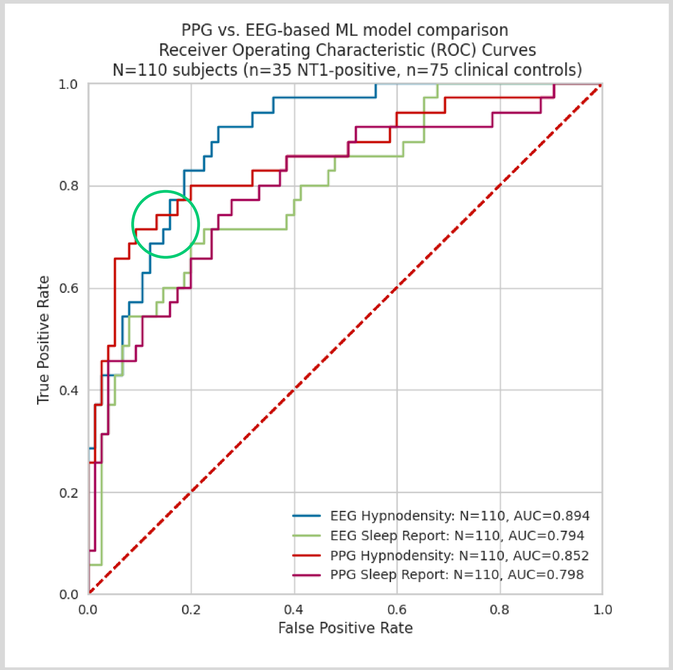


Figure 1. ROC-AUC of 0.852 w/ PPG-Hypnodensity RandomForest

Prior Work: EEG-based NT1 detection using Deep Learning

ROC curves for EEG-Hypno , EEG-Report, and EEG-DeepLearning

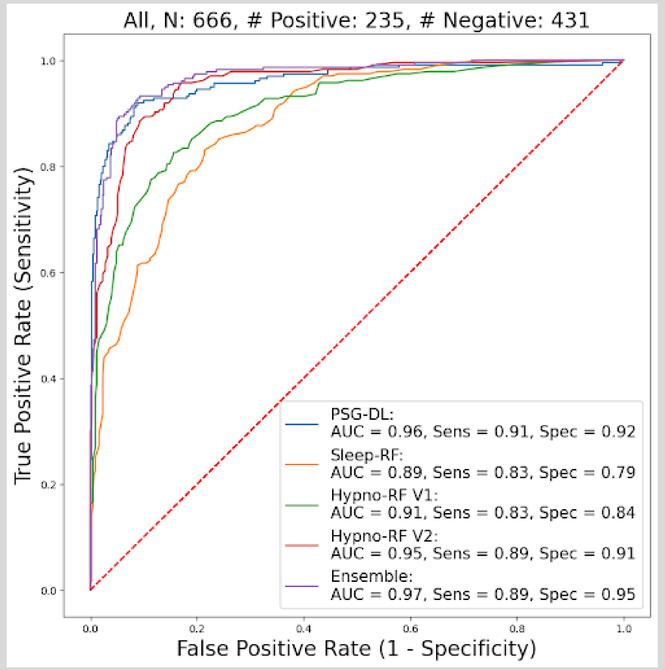


Figure 2. ROC-AUC of 0.96 for best performing EEG-based model (DL)

PPG-enabled NT1 screening and flagging in routine diagnostic HSATs (Types III and IV): Proof-of-concept applications

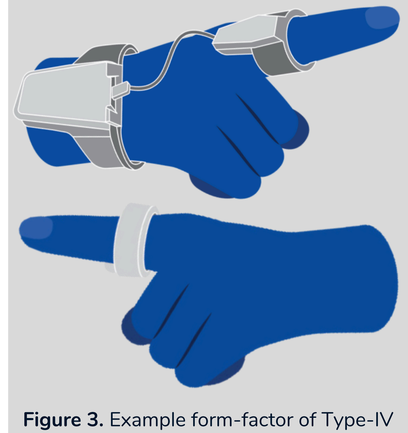
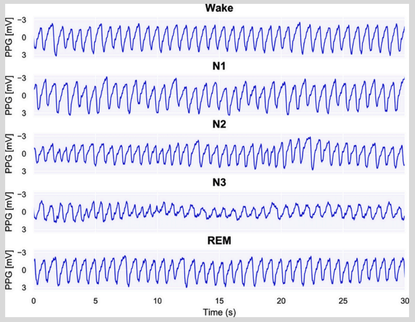
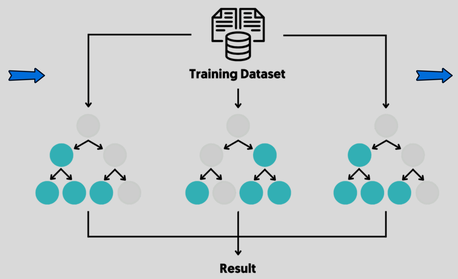


Figure 3. Example form-factor of Type-IV HSAT devices including PPG sensors and signals. The potential app to flag NT1 in HSATs spans indeterminate / negative HSATs, evaluation of residual sleepiness post-OSA therapy, detection of co-morbid NT1 with other sleep disorders, and other use cases.



Category	n	Sensitivity	Specificity	Rosenberg [14]
Wake	74,850	87.8% (87.6%, 88.0%)	93.7% (93.5%, 93.8%)	84.1%
Light Non-REM	107,325	80.7% (80.5%, 80.9%)	86.7% (86.5%, 86.9%)	85.2%
Deep Non-REM	14,166	67.9% (67.1%, 68.7%)	95.5% (95.5%, 95.6%)	67.4%
REM	21,934	84.2% (83.7%, 84.7%)	97.5% (97.5%, 97.6%)	90.5%
Total	218,275	n/a	n/a	n/a



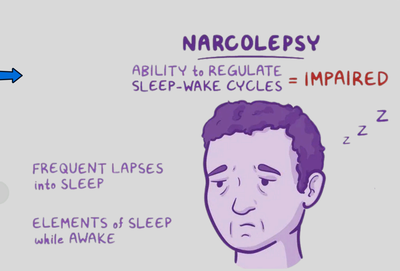


Figure 3. PPG-based NT1 detection – ML Algorithm Pipeline

PPG signals (left) were processed into PPG-based Sleep Stages using an FDA cleared algorithm (mid-left). The PPG Sleep Stages were used to calculate the Hypnodensity plots and Report Parameters (lower-right), and input to a Random Forest model to detect NT1 (positive vs. normal).

PPG-Hypno RF	Sensitivity (%)	Specificity (%)
High-Specificity	66% (23/35)	95% (71/75)
Balanced Sen-Spec.	80% (28/35)	80% (60/75)
High-Sensitivity	86% (30/35)	62% (47/75)

Feature Rank (Gini)	EEG-Report RF	PPG-Report RF
#1	**Sleep Latency**	**SL** (EEG #1)
#2	**Total N3 Time**	**REML** (EEG #5)
#3	**N3 Prevalence**	**N3T** (EEG #2)
#4	**Total Sleep Time**	**N3P** (EEG #3)
#5	**REM Latency**	**TST** (EEG #4)

Conclusions

ML methods automatically detected NT1 in EEG and PPG with comparable degrees of accuracy. The PPG sensor offers a simple and accessible modality in an ecologically valid at-home setting. This method demonstrates potential for screening of NT1 in routine HSATs, whereby patients with NT1-associated sleep architectural characteristics may be flagged for hypersomnolence disorders evaluation and testing. Future work involves optimization of Deep Learning-enabled PPG-NT1 models.