Prediction of Response Time and Vigilance Score in a Sustained Attention Task from Pre-trial Phase Synchrony using Deep Neural Networks

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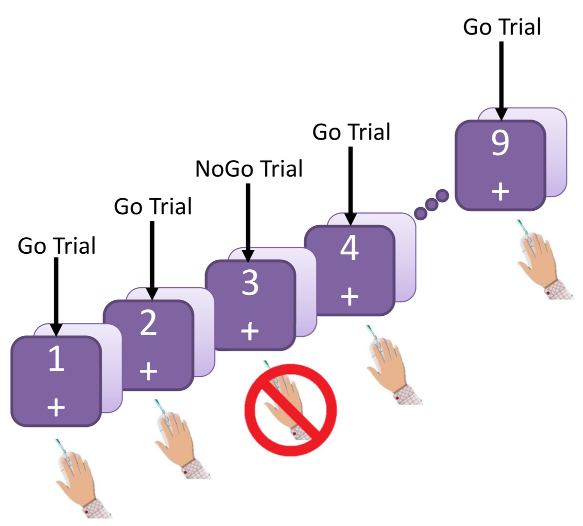
MOTIVATIONS

- Assessment of vigilance is critical in long BCI experiments, ADHD diagnosis, air traffic monitoring, and long-haul driving.
- Current vigilance labeling methods are usually subjective or require facial videos.
- People demonstrate large differences in their response styles (accuracy-speed tradeoff) and the ability to maintain their performance levels.
- Spatial correlates of EEG signals are rarely used to *predict* continuous vigilance scores and response time in long experiments.

CONTRIBUTIONS

1. Using Deep Neural Networks (DNNs) for modeling tonic vigilance scores in long sustained attention tasks from spatial relationships of EEG signals, and
2. Introducing an objective performance-based measure for vigilance labeling

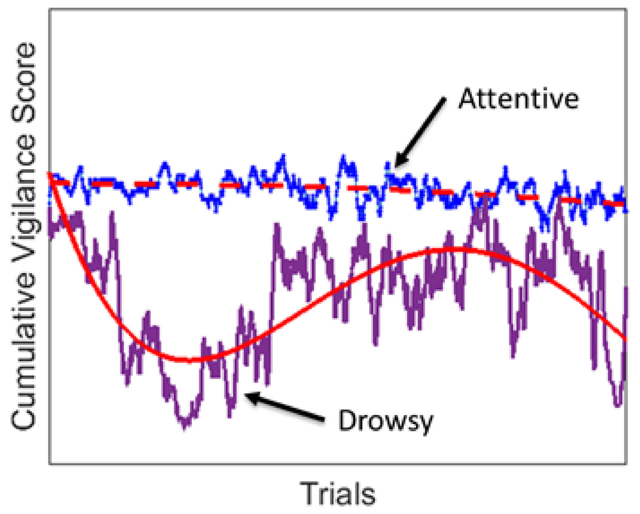
EXPERIMENT DESIGN



- Ten participants; average age 30.25 ± 6.95 years
- Fixed-sequence Sustained Attention to Response Task
- 12 blocks of 225 digits (trials) with varying inter-stimulus intervals
- Task lasting for 105 to 110 minutes
- 64-channel EEG, Biosemi ActiveTwo system @ at 2048 Hz
- Automatic artifact removal, back-propagation, and reconstruction:
  - Each block band-passed from 1 to 70 Hz,
  - Ocular artifact removed using linear combination of simultaneously recorded EOG signals, and
  - Using the Logistic infomax ICA algorithm, ICs removed if exceeding ± 9 SD from their mean.

ADAPTIVE VIGILANCE LABELING

- Five-level Trial Vigilance Score (TVS)
  - TVS = 4 for correct double clicks and very fast and correct responses (RT < 50 ms),
  - TVS = 3 for correct responses (RT< lowerRT)
  - TVS = 2 for correct responses with lowerRT < RT < upperRT
  - TVS = 1 for wrong clicks, slow responses (RT > upperRT), and for double click trials followed by a missed response.
  - TVS = 0 for single missed responses.
- lowerRT = 250 ms, and upperRT = mean + 2 SD of RT from the first 27 trials
- Cumulative Vigilance Score (CVS) obtained from a weighted moving average of 4 sequences (∼ 73 seconds).



Comparison of CVS curves from different response styles

PHASE SYNCHRONY INDICES

- Digit-locked epochs, [-200, 1,600] ms, downsampled to 512 Hz.
- Epochs band-passed to alpha, lower beta-1 and 2, mid-beta, upper beta, wide-band beta, and wide-band gamma.
- Averaging pairwise phase differences for all $N = 225$ trials of a single block using Hilbert transform:

$$x_{HT}(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{x(t')}{t-t'}dt', \quad t \in \{1, 2, ..., 923\},$$

$$\Phi_{ij}(t,n) = \Phi_i(t,n) - \Phi_j(t,n), \quad i,j = 1,2,...,64,$$

$$PLV_{bk}(t) = \frac{1}{N}\left|\sum_{n=1}^{N} e^{j\Phi_{ij}(t,n)}\right|, \quad N = 225.$$

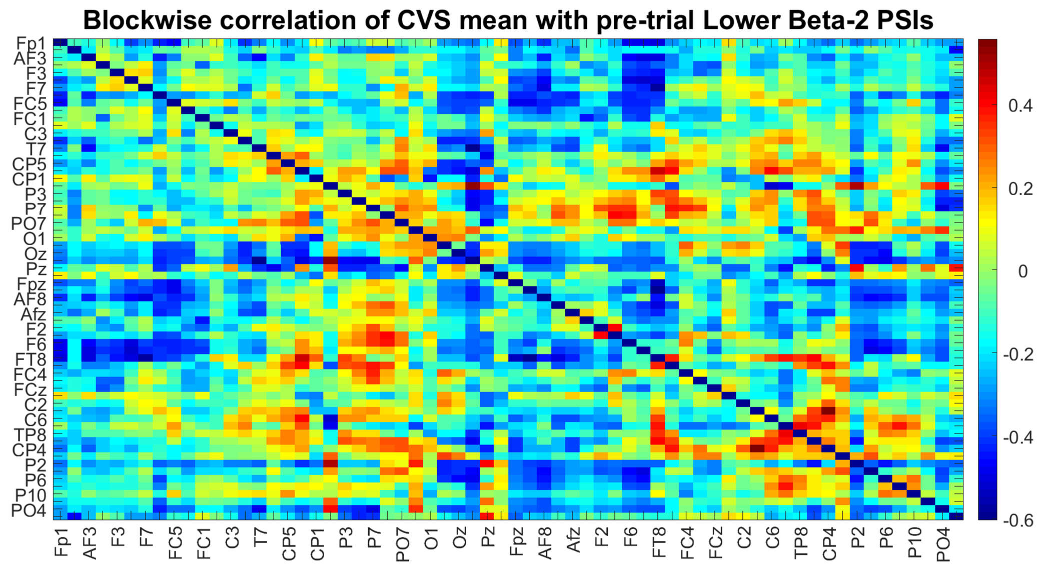
- Block-wise features extracted from samples 1 to 103 in the pre-trial epochs, resulting in 64×64 images:

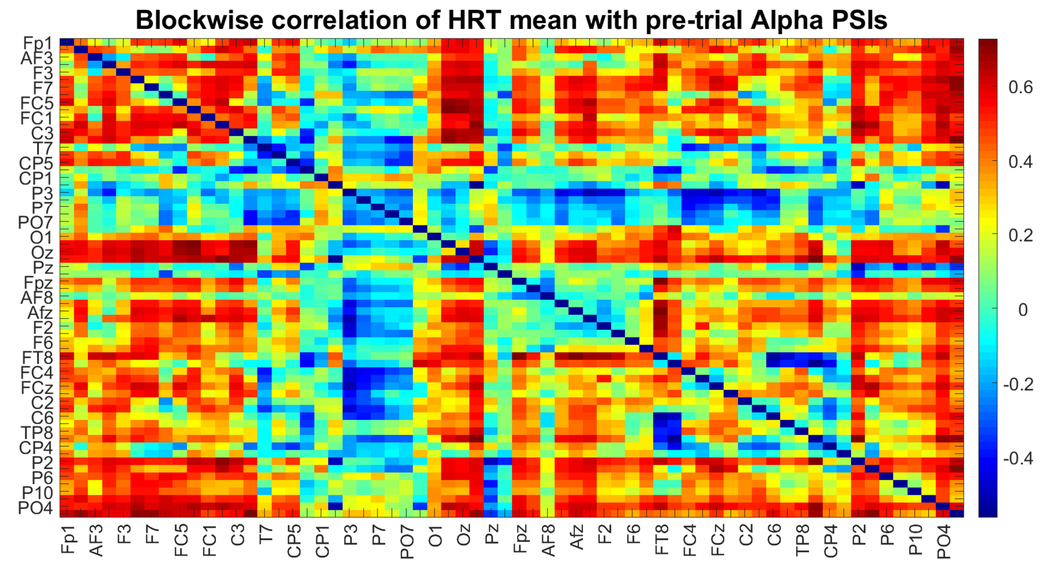
$$PSI_{bk} = \frac{1}{T}\sum_{t=1}^{T} PLV_{bk}(t).$$

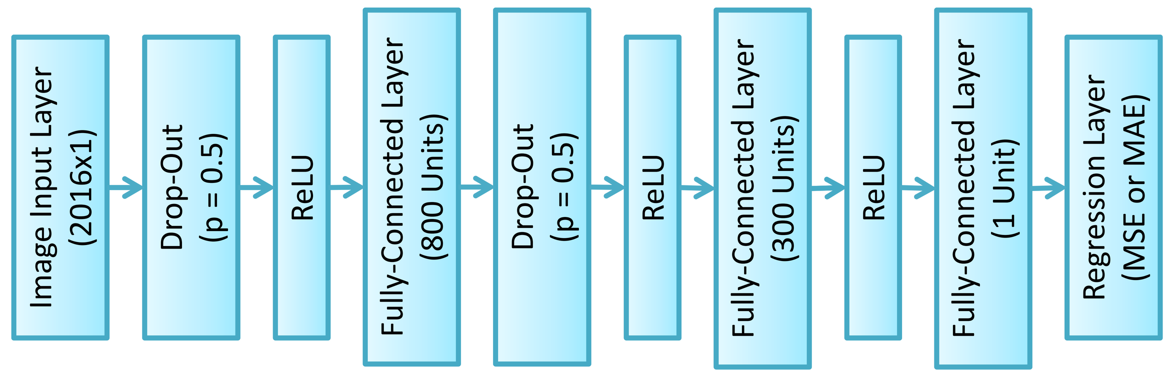
- Dataset X: 2016 unique values and 113 SART blocks.

REGRESSION WITH DNNS

- As a subset of neural correlates of pre-trial EEG, phase synchrony indices bear meaningful correlations with blockwise performance measures:

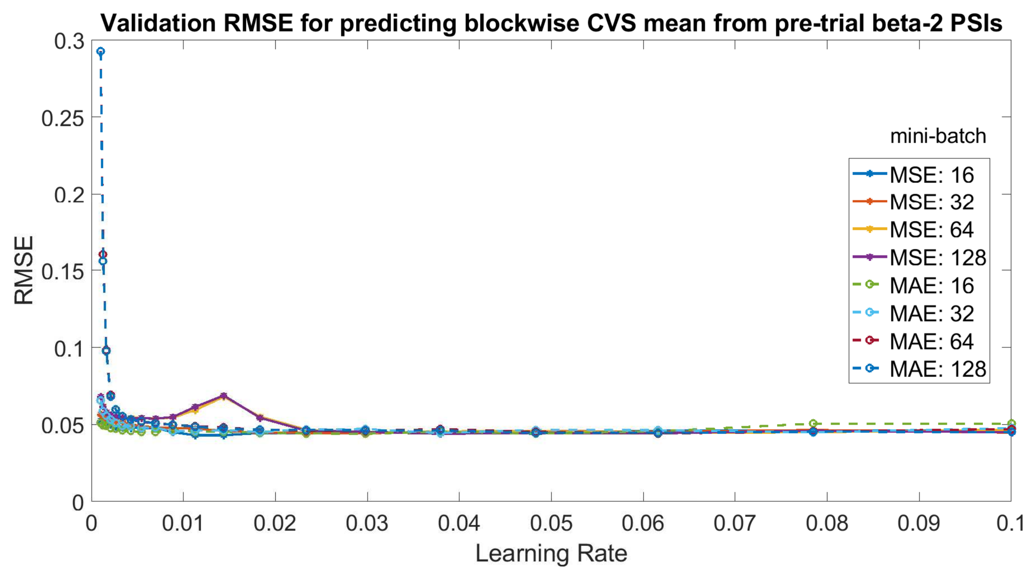


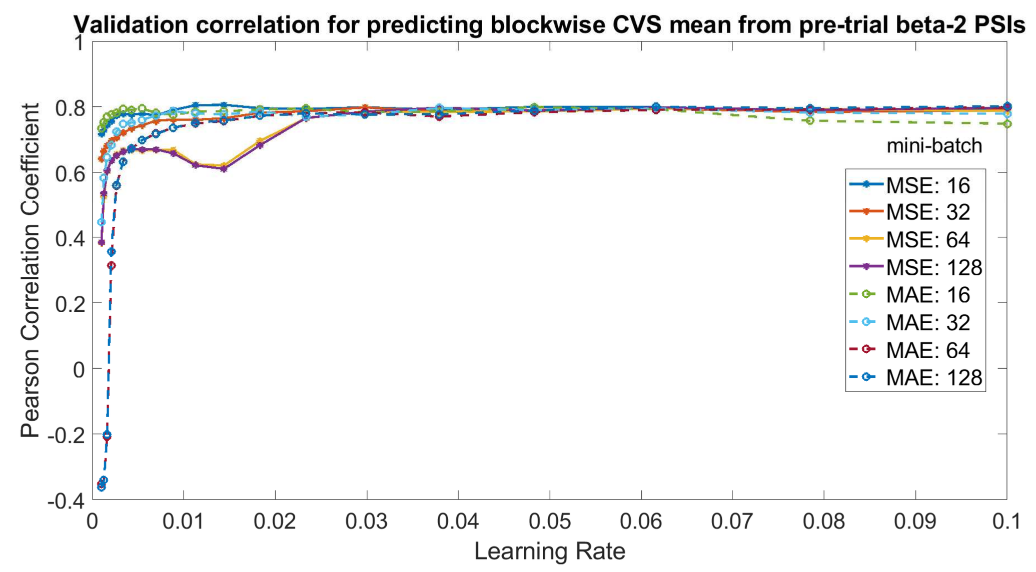




To predict block-wise CVS mean and hit response time mean from 7 frequency bands:

- Two cost functions utilized for regression: MSE and MAE
- Grid search for 20 learning rate values from 0.001 to 0.1 and mini-batch sizes of 16, 32, 64, and 128
- Networks trained for 5 runs and 4-fold cross-validation with stochastic gradient descent for 150 epochs





CONCLUSIONS

- Stronger asynchrony in frontal cortex and from left centro-temporal with midline parieto-occipital, and synchrony within the right centro-tempo-parietal cortex are correlates of improved CVS.
- Alpha synchrony in the left fronto-central, with the right posterior channels, and within the right parieto-occipital cortex are strong correlates of delayed responses.
- Results are in line with roles of alpha and beta coherence in alertness to fatigue transition, attentional processes, and motor learning.

ONGOING RESEARCH

- Development of multivariable regression models for prediction of overall performance scores in a long SART session from pre-task, resting-state EEG features
- Classification of drowsy versus alert states from trial-based spatio-spectro-temporal features using convolutional neural networks (CNNs)
- Modeling the temporal structures, prediction, and adaptation of vigilance scores using recurrent neural networks (RNNs)

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ACKNOWLEDGEMENT

This work is supported by the grant number 116E086 from the Scientific and Technological Research Council of Turkey (TÜBİTAK).

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