Adaptive probabilistic regression for real-time motor excitability state prediction from EEG

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Lisa Haxel[1,3,4], Jaivardhan Kapoor[1], Ulf Ziemann[3,4], Jakob H. Macke[1,2]

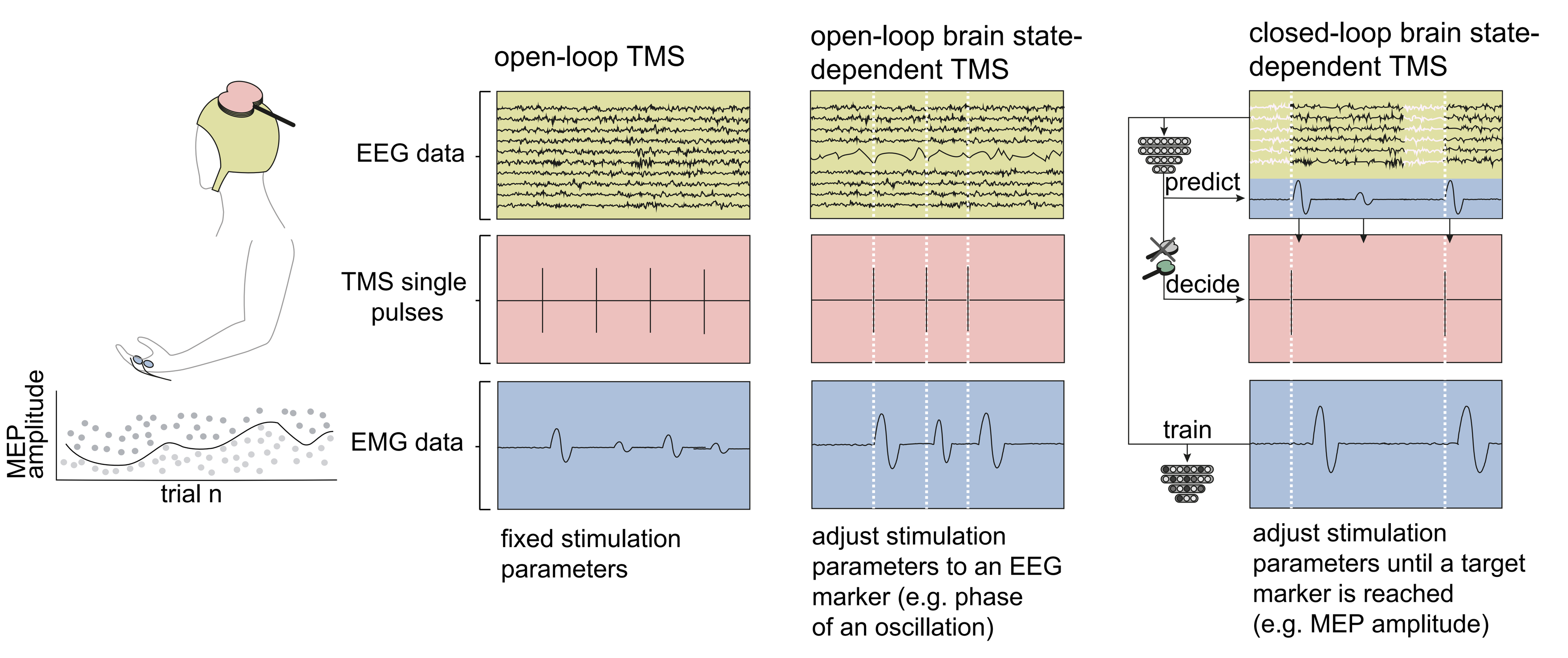
[1] Machine Learning in Science, Excellence Cluster Machine Learning, University of Tübingen & Tübingen AI Center, Tübingen, Germany
[2] Department Empirical Inference, Max Planck Institute for Intelligent Systems, Tübingen, Germany
[3]Hertie Institute for Clinical Brain, Tübingen, Germany [4]Department of Neurology and Stroke, University Hospital Tübingen, Germany

contact: lisa.haxel@uni-tuebingen.de

Why does the brain's response to repeated identical TMS pulses vary and why does it matter?

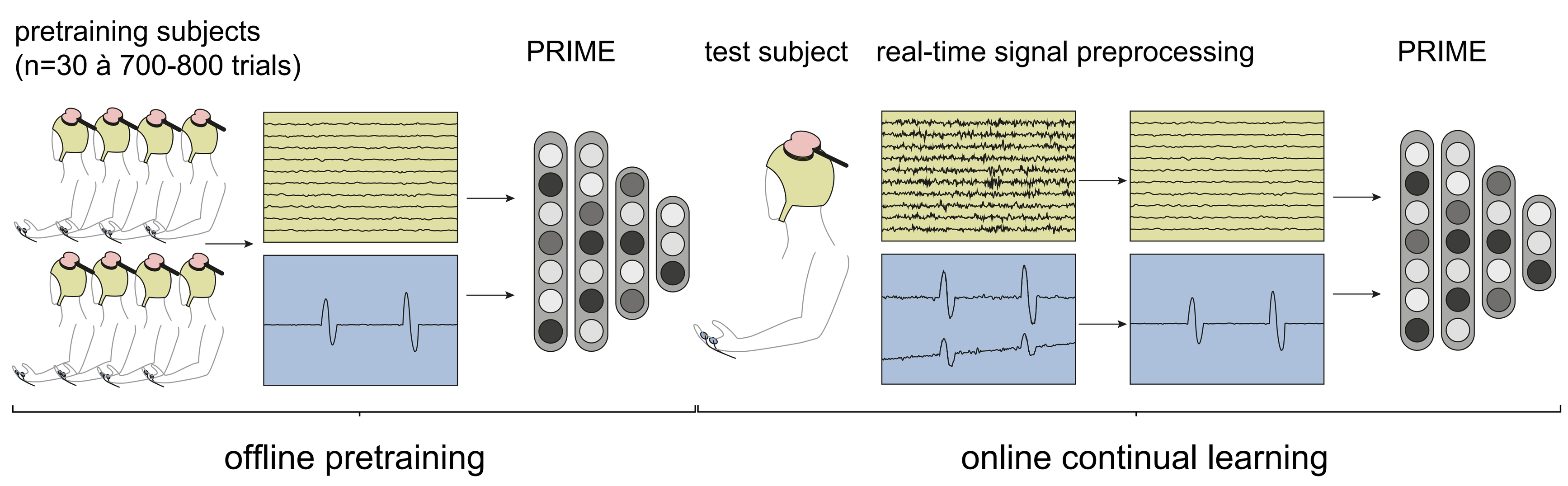
- Transcranial magnetic stimulation (TMS) is widely used in brain research and treatment of brain dysfunctions.
- TMS effects are dependent on the instantaneous brain excitability state.This leads to large variability in immediate and longer-term stimulation responses.
- Exploiting this variability through personalized adaptive brain state-dependent TMS can optimize the efficacy of TMS applications across different clinical conditions [1].

Our goal: From open-loop TMS to **machine learning-based closed-loop brain state-dependent TMS**

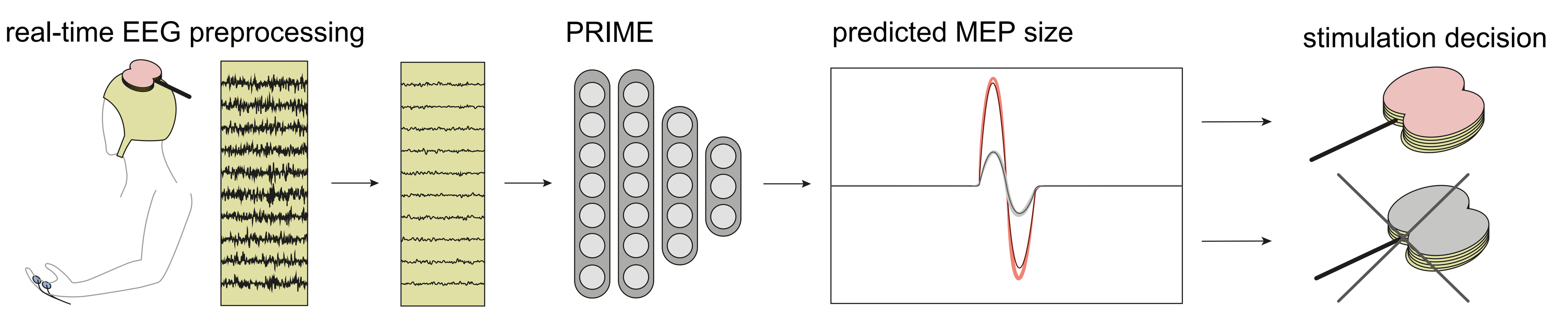


Our approach: PRIME
(**P**robabilistic **R**egression for **I**nferring **M**otor **E**xcitability)

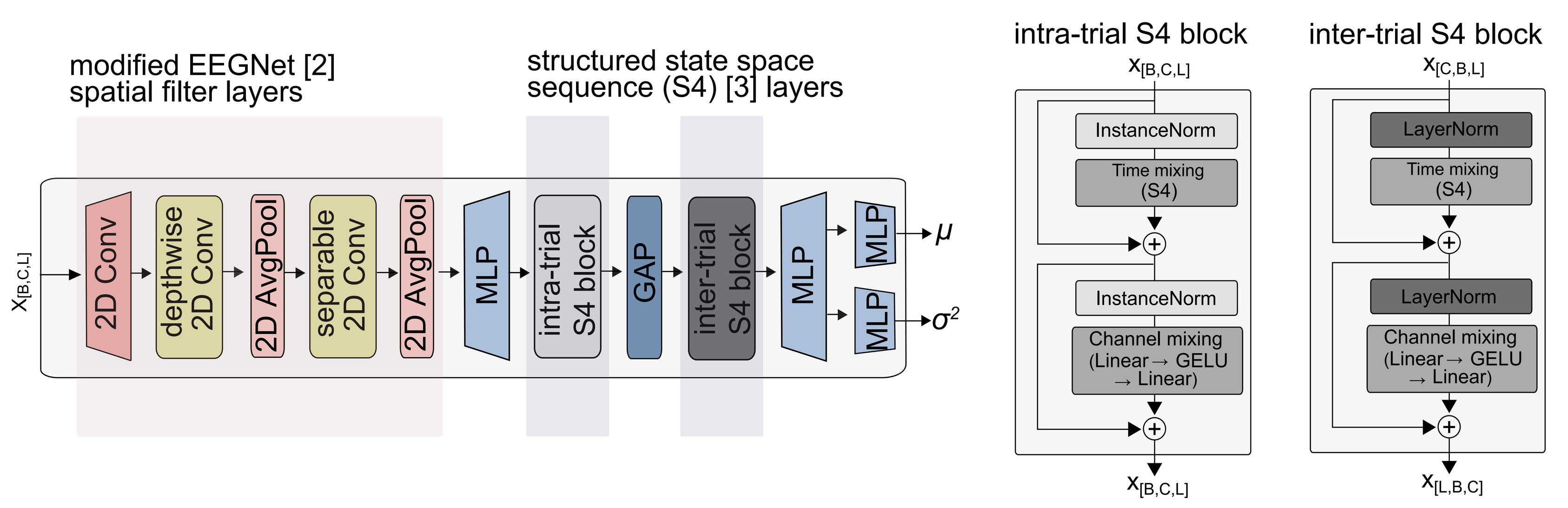
Model training: Transfer learning & real-time expanding window continual finetuning



Next trial MEP prediction and stimulation decision

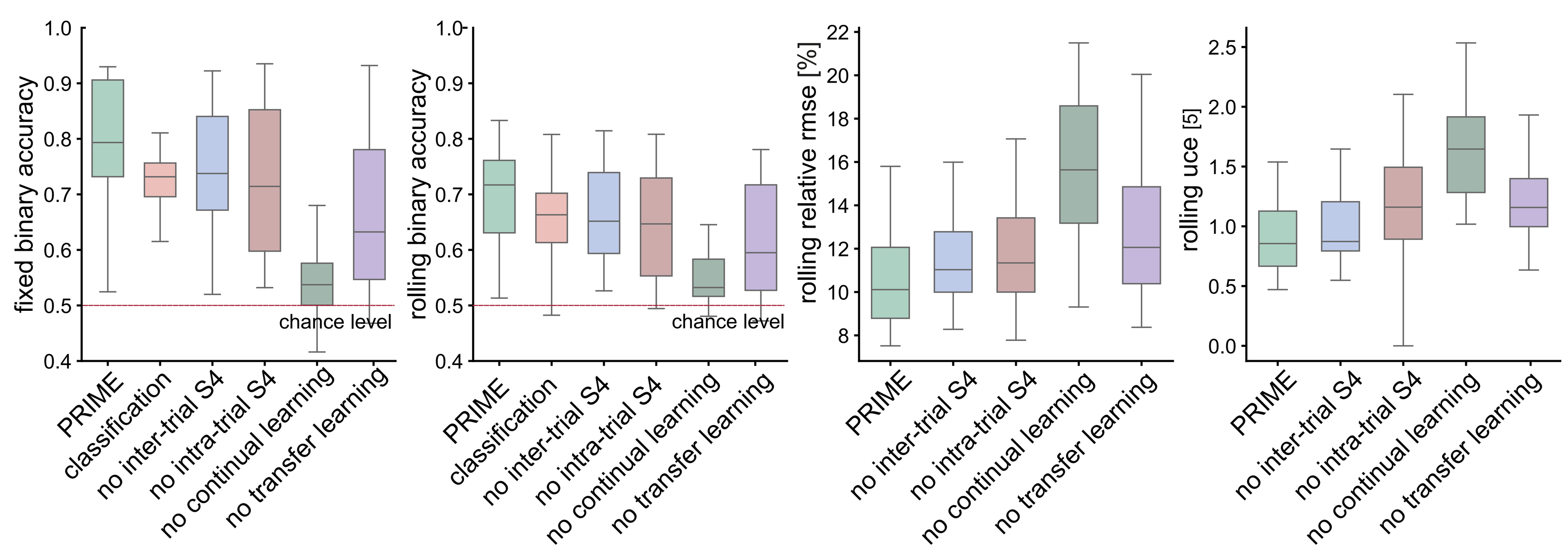


Model architecture

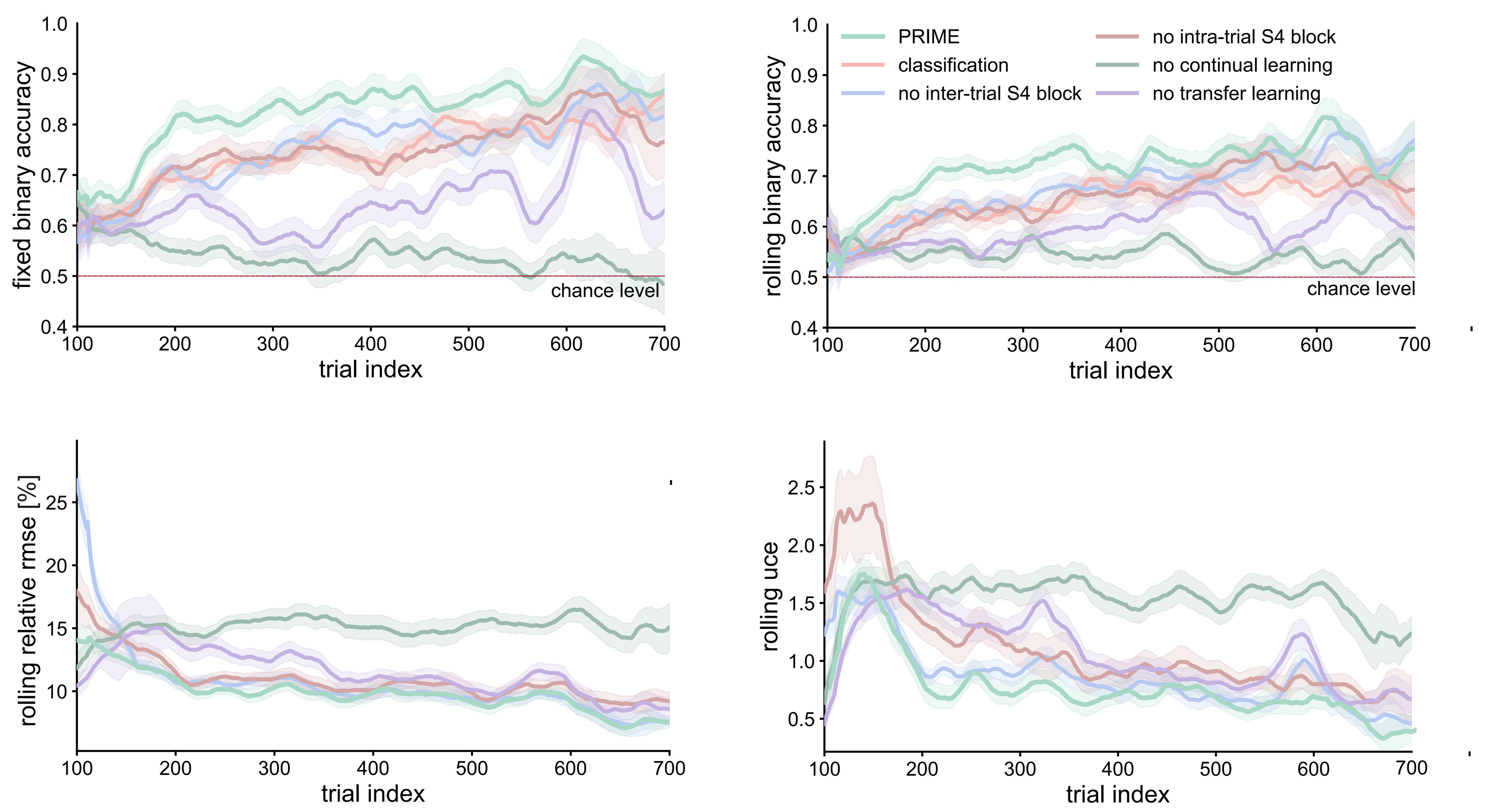


PRIME demonstrates higher prediction performance than ablated versions

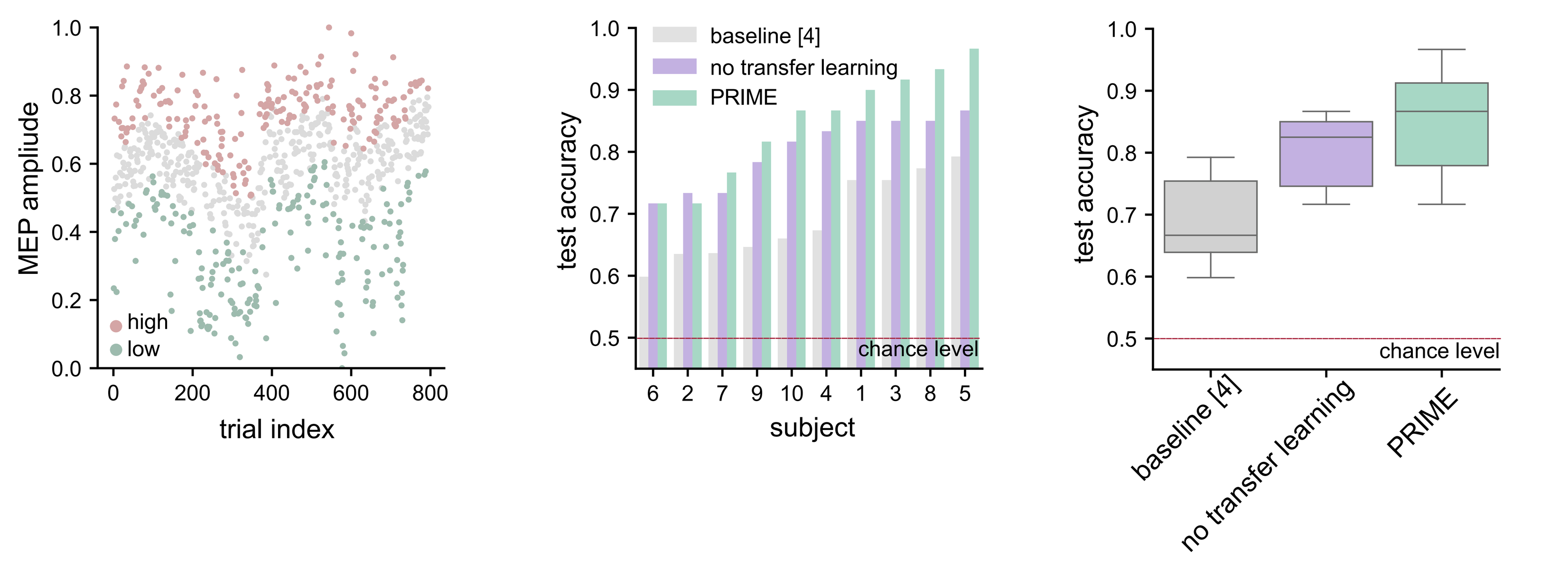
Aggregate prediction performance



Trial-by-trial prediction performance



PRIME shows higher prediction accuracy than non-adaptive baseline



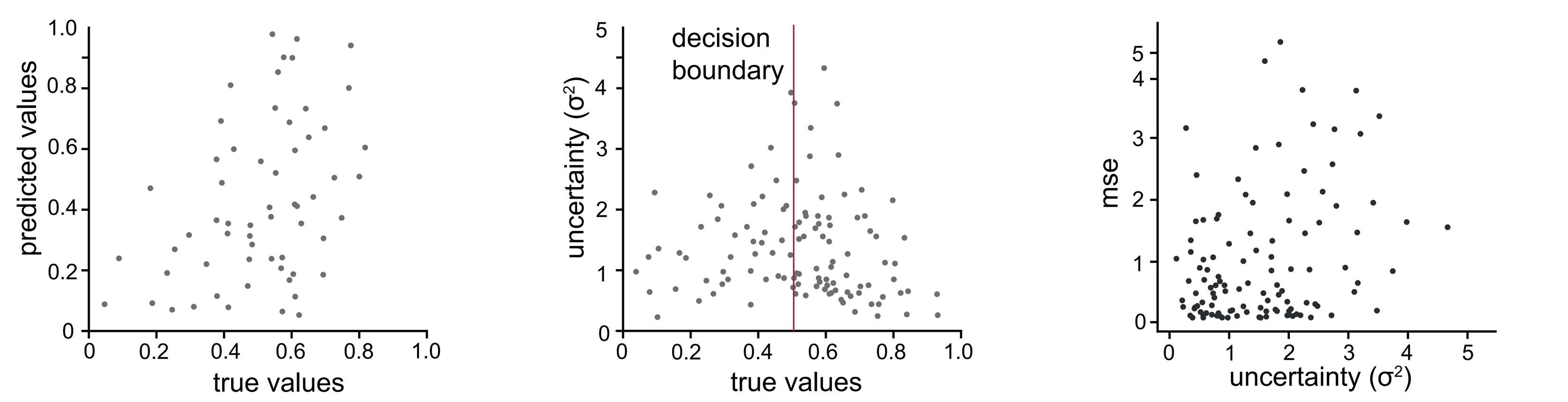
- Baseline: Feature-based binary classification (LR, RF, SVM) with temporal sequential split, limited to the most extreme trials (highest and lowest 200 MEP amplitudes).
- Differences in prediction performance between subjects from the same dataset are consistent across methods.

Model uncertainty analysis of an example subject

Predicted responses closely match true responses

Predicted uncertainty is highest near the decision boundary

Predicted uncertainty is calibrated with prediction error



[1] Humaidan et al., (2024) [2] Lawhern et al., (2018) [3] Gu et al., (2021) [4] Haxel et al., (2024) [5] Laves et al., (2021).

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Summary

- PRIME is an end-to-end deep probabilistic convolutional neural network for predicting motor excitability states from EEG signals in real-time
- PRIME shows promise for enhancing TMS neuromodulatory effects in closed-loop brain state-dependent brain stimulation interventions