Somatosensory Signal Detection Behavior Classification with Machine Learning Approaches

COLUMBIA | ENGINEERING
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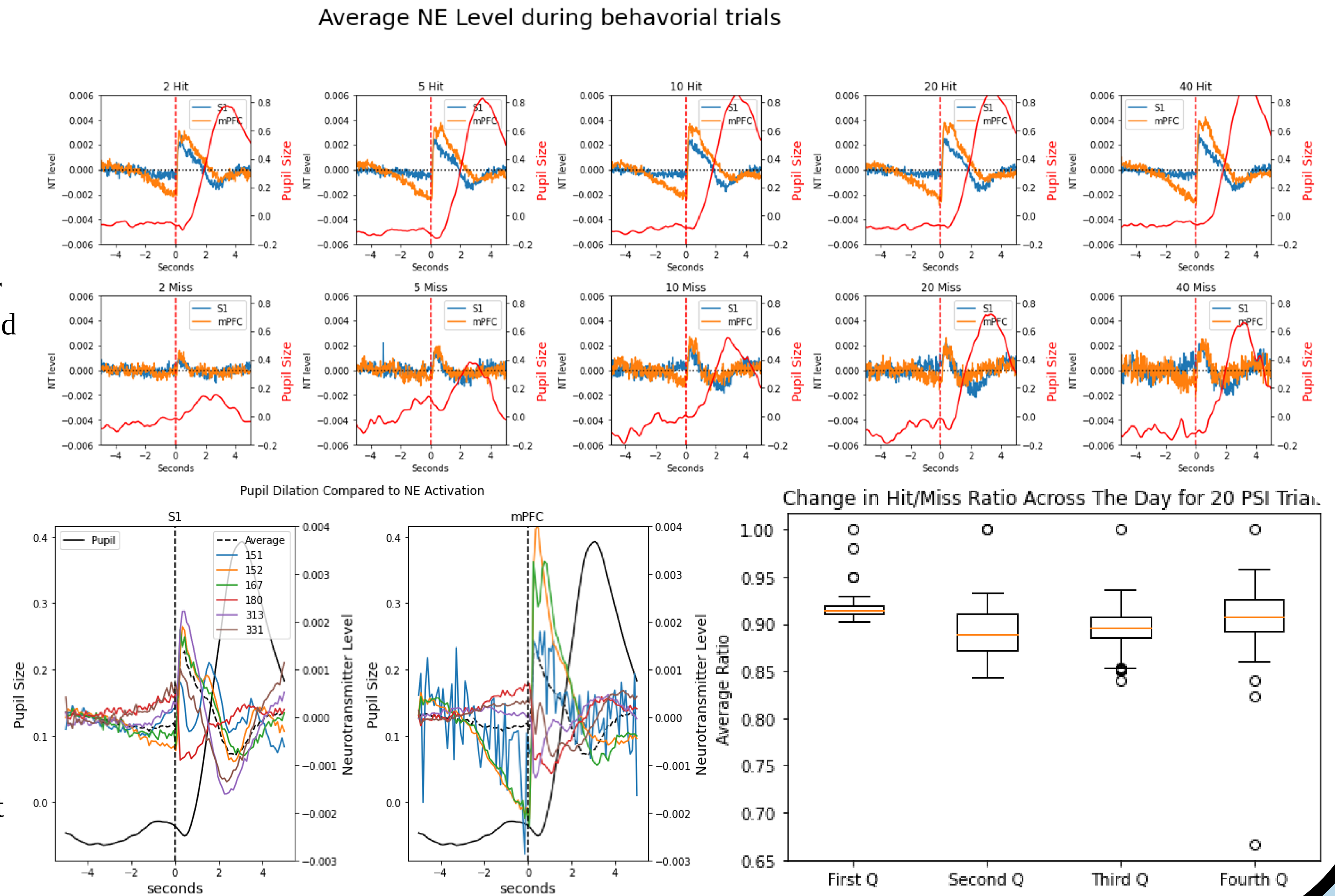
Introduction

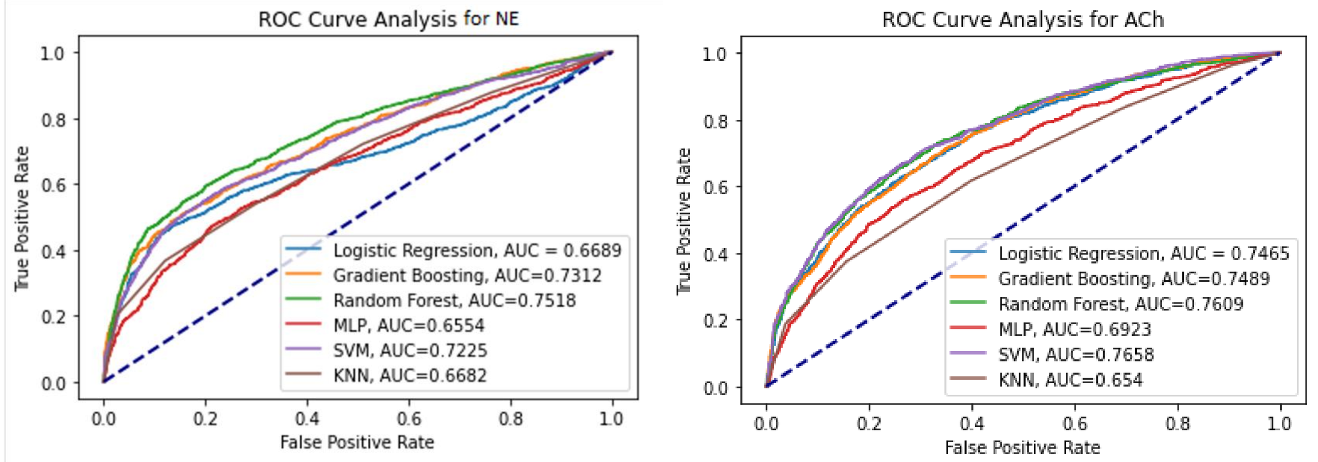
- Neuromodulator systems such as Norepinephrine (NE) and Acetylcholine (ACh) have predictable phasic patterns and play a critical role in sensory discrimination behavior.
- Future attempts to derive control systems for somatosensation will require an understanding of these neuromodulator dynamics.
- Prior evidence shows consistent pupil physiological responses prior to behavior and thus an indirect correlate to neuromodulator activity. We first hypothesized that neurotransmitter levels preceding stimulation could predict mice response.
- Additionally, given previous findings that GCAMP intensity was related to stimulation strength, we predicted data post stimulation would predict stimulation PSI.
- We expect more complex models will have greater performance due to their ability to extract non-linear features.

Behavior

- Across all animals there was not a significant decrease in performance throughout experimental days, however there was an increase in variability.
- As expected, neuromodulator activity (ACh then NE) lagged peak pupil size during stimulation.
- There was a large heterogeneity in neurotransmitter dynamics across all animals.
- There was also consistent dynamics between hit and miss trials with a clear difference in waveform.
- There was no difference in dynamics between trials with different PSIs besides a slight increase in peak amplitude.

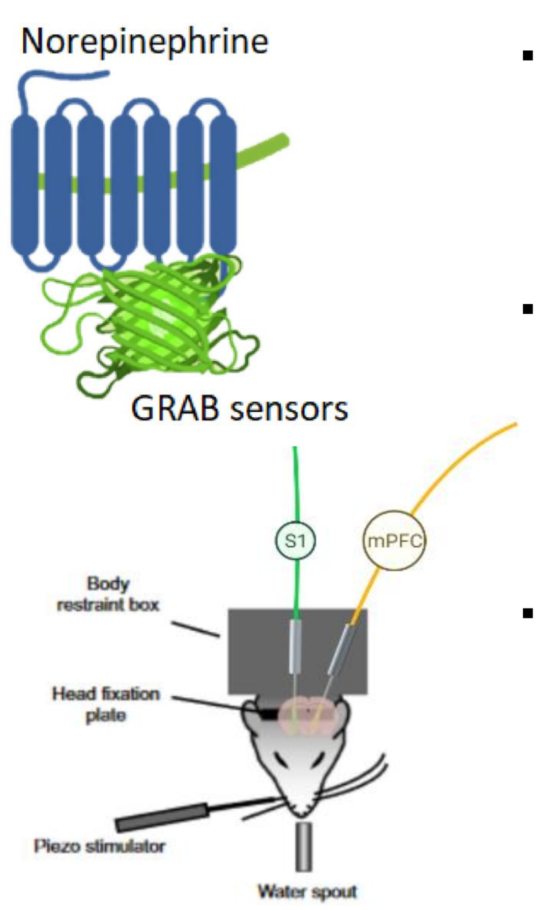


Results

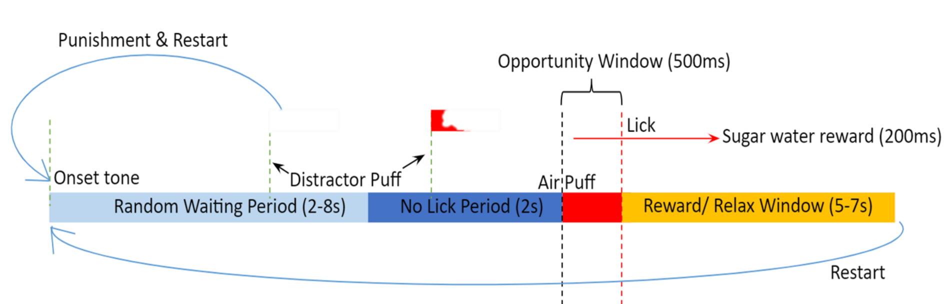


- When trained on individual animal's, logistic regression reached 88% accuracy at peak for logistic regression and 91% accuracy for MLP to predict behavior.
- When trained on all animals at once accuracy reached 76% at peak.
- Attempting to predict PSI failed with only 25% accuracy, compared to 16% random chance.
- Both LSTM and ESN models converged to minimal loss during training, however LSTM only reached 44% accuracy.
- ESN reached 88% accuracy at peak however due to a large variability it reached 68% accuracy on average.

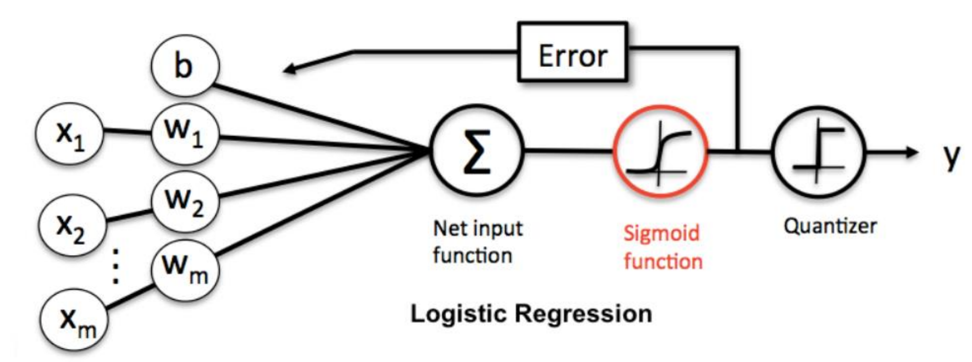
Methods

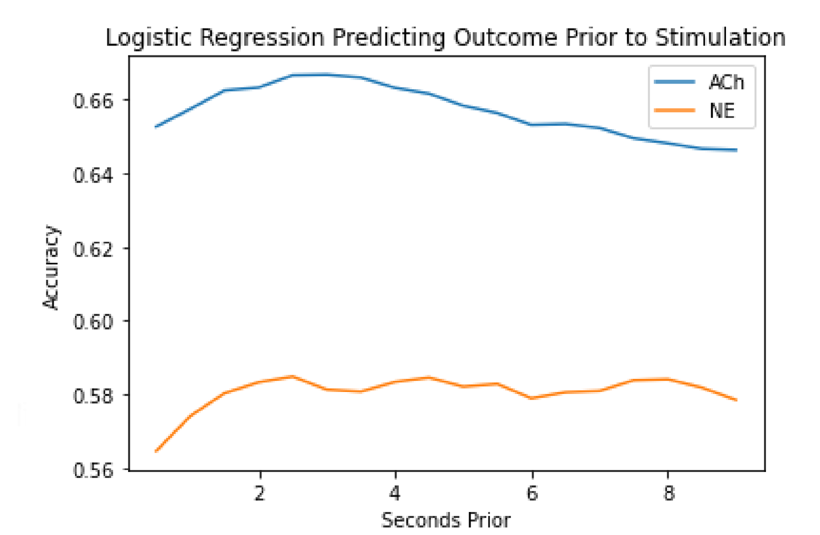


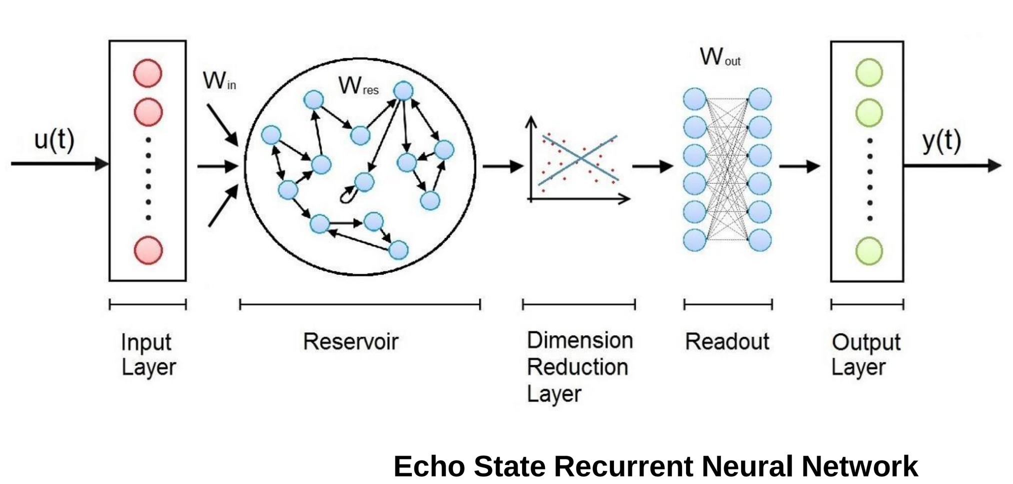
- Mice expressed GPCR-activation based NE and ACh fluorescent receptors which enabled *in vivo* photometry recordings with high temporal resolution.
- Mice (n=10) had two-photon microscopy recording sites in somatosensory cortex (S1) and medial prefrontal cortex (mPFC) during which head was fixated and whiskers were stimulated with air puffs.
- 40,000 total trials were collected which consisted of a random onset time, followed by an air puff of 0, 2, 5, 10, 20, or 40 PSI and a 500ms window of opportunity to lick and retrieve a reward.

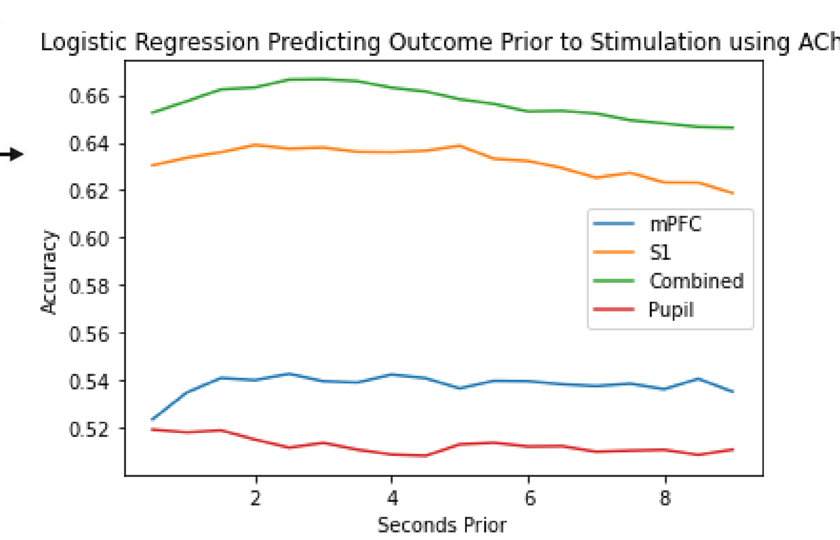


Models









- To predict animal response Hit/False Alarm trials were encoded as 1 and Miss/Correct Rejection trials were encoded as 0.
- Each data point for S1 and mPFC was a single feature: 2 seconds of photometry * 120 Hz sampling rate * 2 brain regions = 480-time dependent features.
- Logistic regression was used as a first pass simplistic model to determine if neurotransmitter dynamics could be fitted to a linear curve.
- 2 seconds of data prior to stimulation provided the highest model performance.
- Individually mPFC had a performance of 54% but when combined with mPFC, exceed mPFC alone.
- To fit nonlinear patterns MLP, RF, XGBoost, KNN, and SVC models were tested .
- To extract temporal dynamics Long Short-Term Memory (LSTM) and Echo State Networks (ESN) were used

Conclusions/Directions

- These results show that individual mice's neurotransmitter dynamics immediately prior to behavior can be modeled with a linear S curve, however, to generalize across multiple animals requires deeper networks that incorporate nonlinear temporal filtering in RNNs.
- Even though prior data could predict action, it remains unclear why photometry data prior to stimulation is predictive of action when the trials should be randomized, therefore more research needs to examine the potential of animals learning/expecting stimulation over time.
- Deeper models could be attempted to reach higher generalized accuracy such Multivariate CNNs, but more importantly more data should be used to optimize LSTM/ESN architecture and hyper parameters.

References / Acknowledgements

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