Neural Coding of Time during Multi-Whisker Sensation

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INTRODUCTION

Tactile sensation is complex, and how the nervous system encodes tactile input remains poorly understood. Neural coding of tactile sensation is often studied through the rodent whisker system. Prior studies focused on coding of single whisker deflections. The standard model of these studies is that primary somatosensory cortex (S1) neurons are tuned for a specific preferred whisker. However, single whisker deflections are not reflective of natural stimuli, which consist of complex spatiotemporal patterns of whisker deflection. How these are encoded by the S1 is largely unknown.

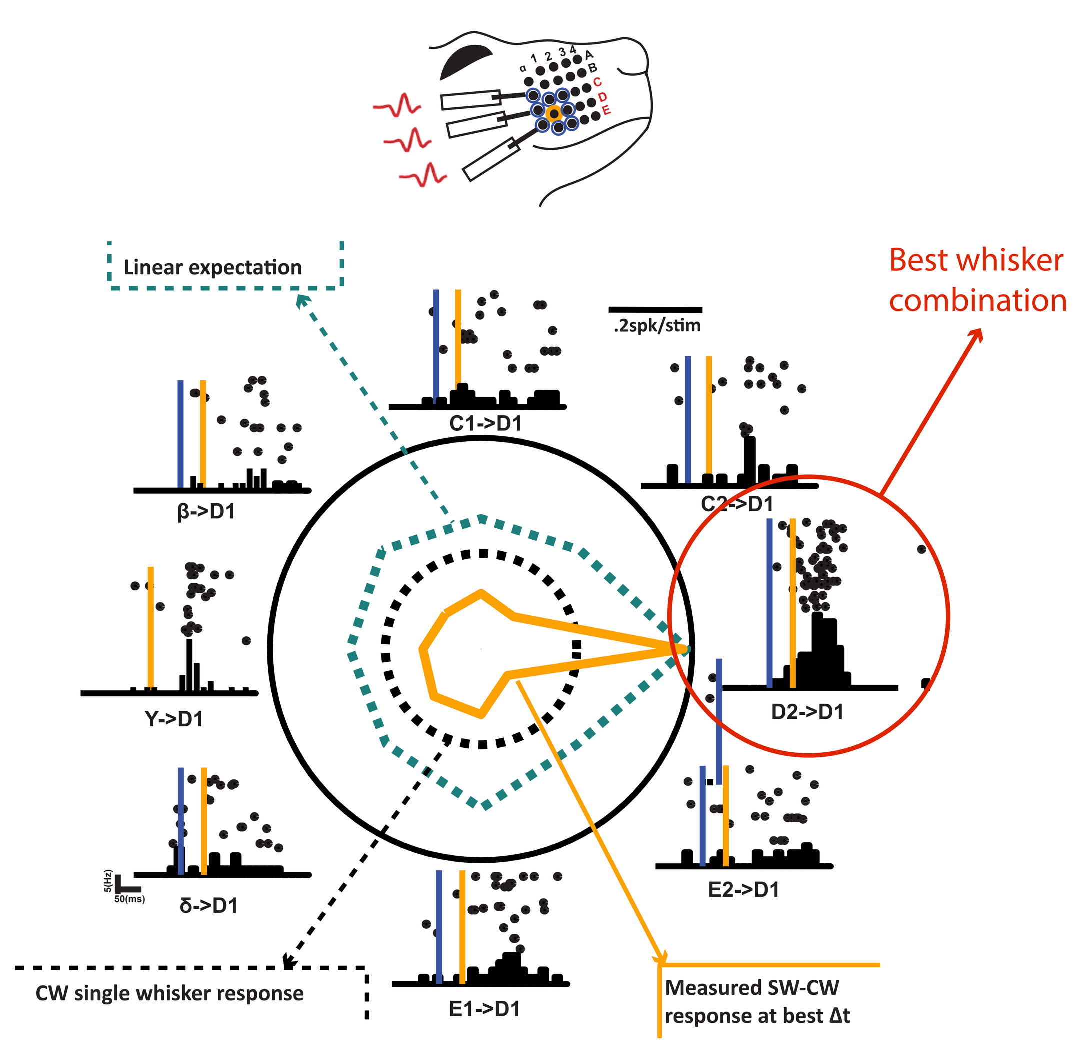

Figure 1: Illustration of mouse whisker deflection, with preferred whisker combinations shown to the right

MAIN QUESTIONS

1. Can time be decoded from single-trial responses by the S1 population, and to what extent?
2. From a rate-coding perspective, what mechanism is used to decode time?
3. How do temporal receptive fields relate to spatial receptive fields in the S1 population?

DATA

Data was recorded from S1 spiking evoked by sequential deflections of different whisker pairs at various inter-whisker deflection intervals (IDIs).

METHODS

- **Tuning-curve estimation from data:** Smoothing using a Gaussian kernel
- **Determination of significant tuning curves:** Benjamini-Hochberg procedure
- **Initial tuning curve analysis:** Principal component analysis
- **Population Model:** A set of independent, overdispersed Poisson processes parameterized by tuning curves. Overdispersion was modeled using a negative binomial distribution.
- **Temporal Decoder:** Multinomial logistic regression model, with LASSO regularization for feature selection. Regularization strength selected through k-fold cross-validation. Test and train sets were independently generated.
- **Resolution estimation:** Louvain method for community detection, applied over confusion matrices generated from the decoder.
- **Layer-wise comparison:** One-Way ANOVA, and Tukey's range test

RESULTS

1. Using a rate code approach, IDIs can be decoded well above chance from single-trial data over the population, with a resolution around 20 milliseconds.

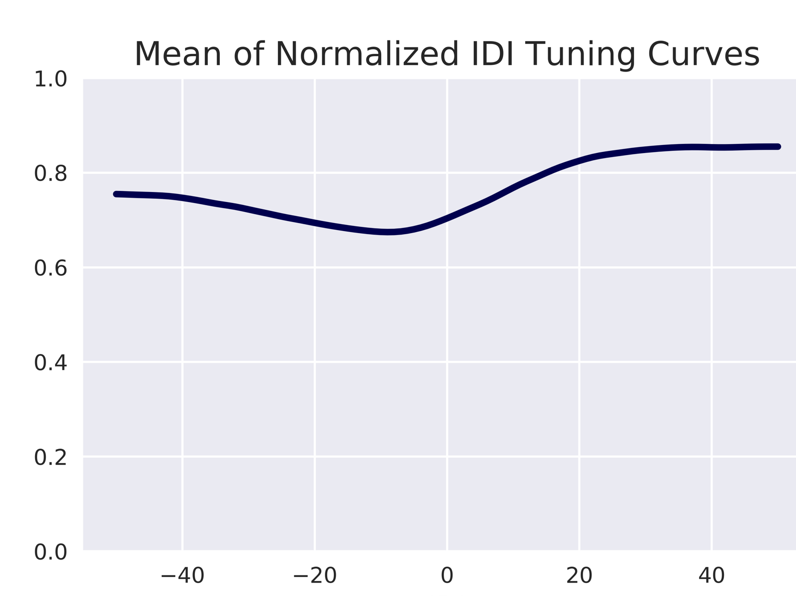

Figure 2a: The normalized mean IDI tuning curve from the data matrix used for PCA.

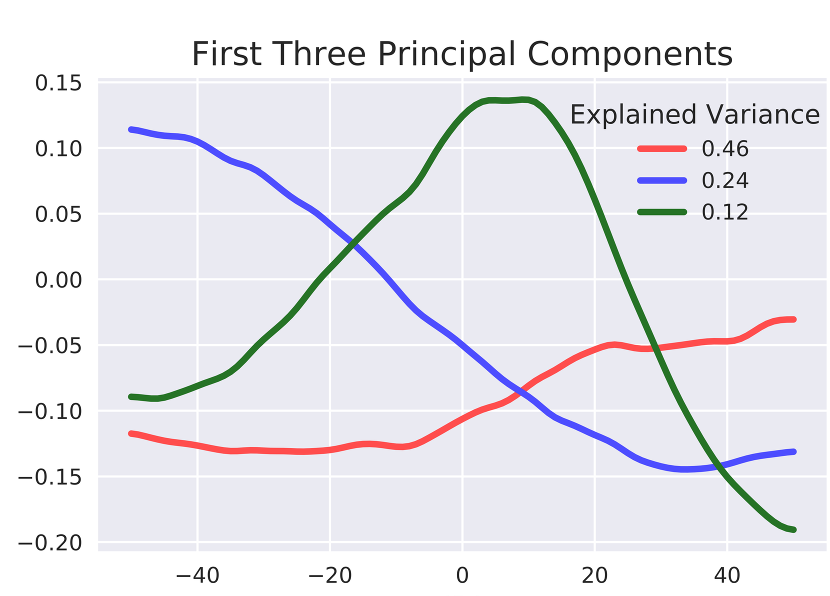

Figure 2b: The first three principal components, capturing 82% of the variance among IDI tuning curves.

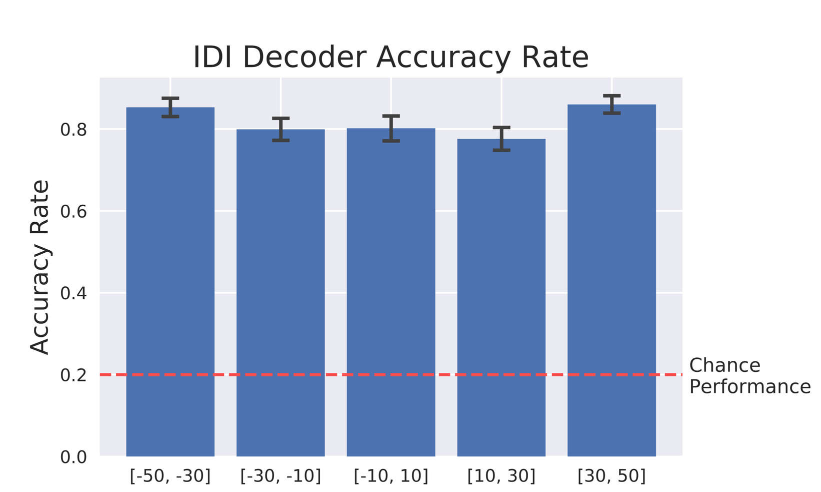

Figure 3a: The accuracy rate of the IDI decoder, with error bars indicating standard deviations.

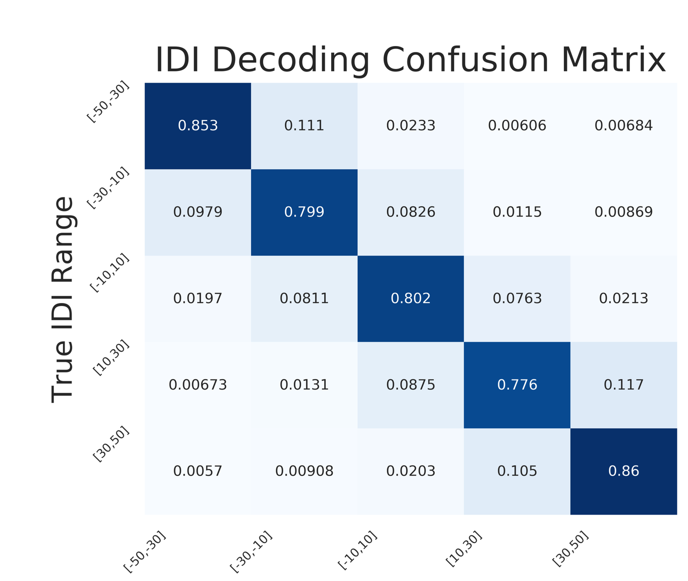

Figure 3b: The mean confusion matrix of the IDI decoder, over 40 trials.

RESULTS

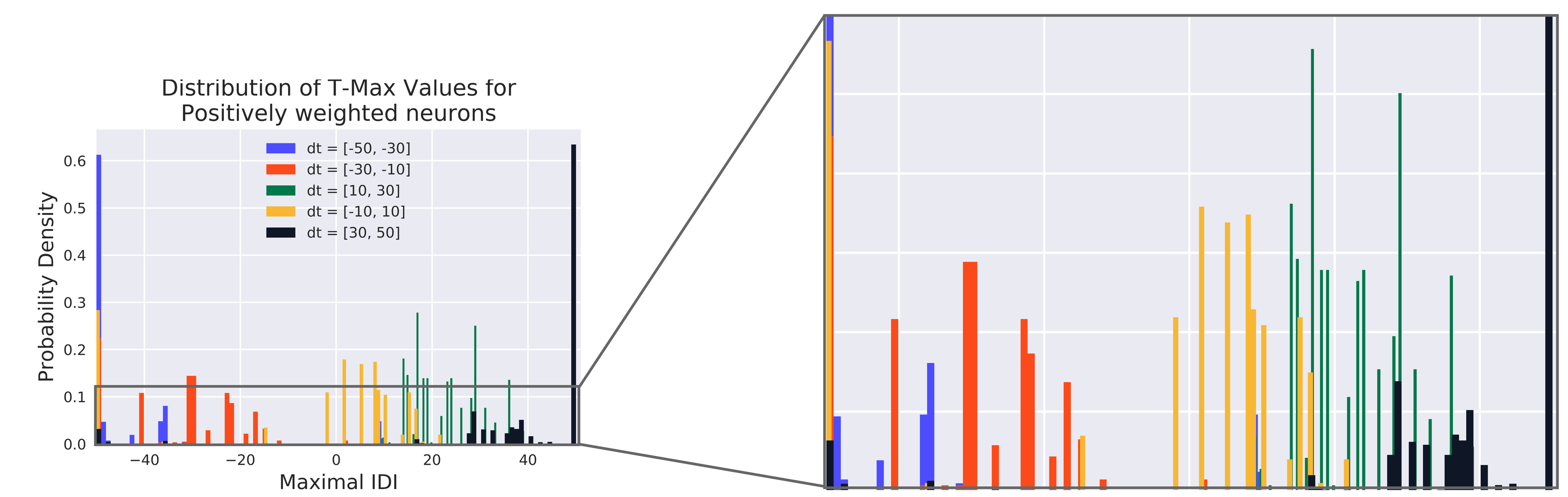

Figure 4: Distribution of neurons at their maximal-valued IDI over the different IDI ranges classified by the decoder.

2. The positively weighted neurons used by the decoder form a basis over IDI when defined by their maximal-valued IDI.

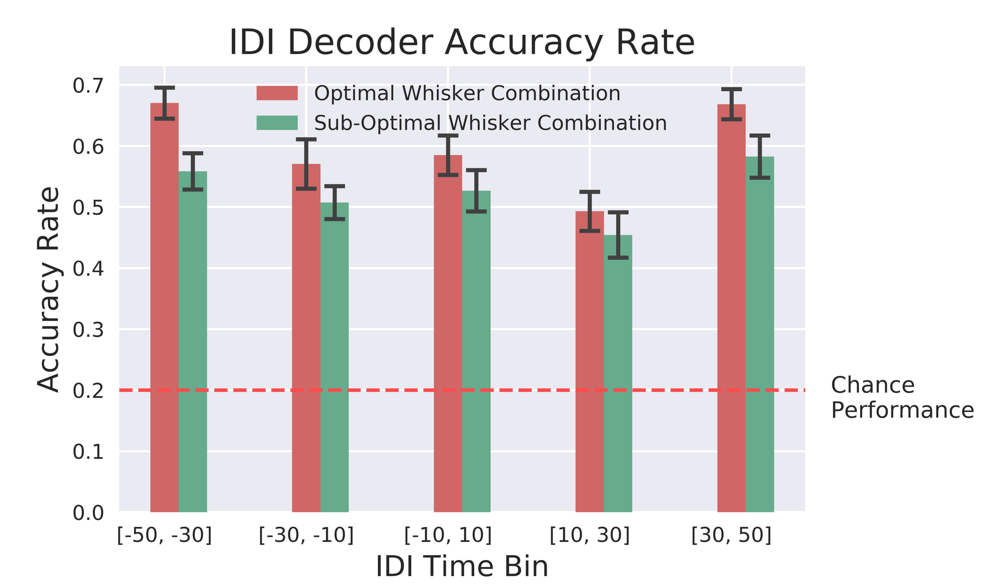

Figure 5: Comparison of decoder accuracy rate when using only optimal whisker combination of each neuron, versus the sub-optimal (second-best) whisker combination.

3. IDI tuning is greatly preserved over the optimal whisker combination (peak of spatial receptive field) of each neuron.

CONCLUSIONS

- The mouse S1 neuron population can encode time at a 20 ms resolution.
- Theoretically, neurons may convey the most information about stimuli at the point in the tuning curve where firing rate changes most steeply. Our results suggest instead that S1 neurons convey maximal information about whisker timing at their best IDI.
- Temporal receptive fields are correlated with spatial receptive fields in the whisker system.

ACKNOWLEDGEMENTS

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