Behaviorally-locked structure in a sensory neural code

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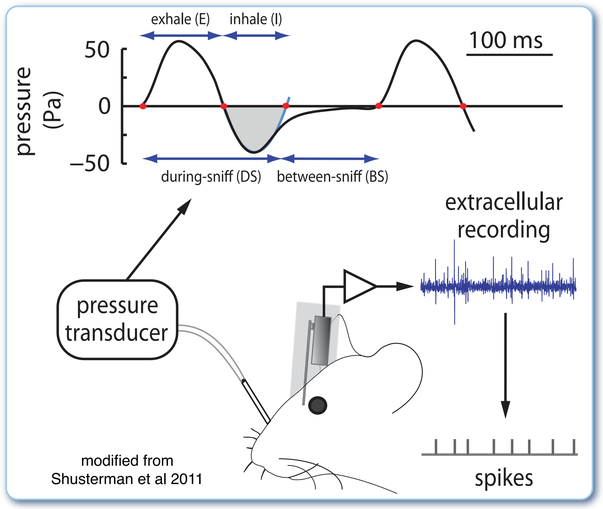
The experiments

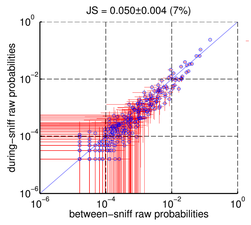


- 9 mitral/tufted cells from an awake, head-fixed mouse
- 10ms bins
- ~950s (95k samples) during-sniff (174±29ms each)
- ~400s (40k samples) between-sniff (75±40ms each)
- all error bars = s.d. after subsampling to 2500 samples 25 times
- all results qualitatively replicated on 2 other data sets (with 9 and 8 cells)

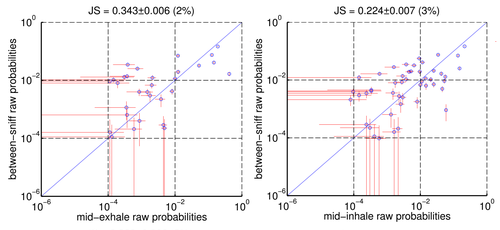
Behaviorally-locked modulation of neural vocabulary

Between- and during-sniff vocabularies are nearly indistinguishable...

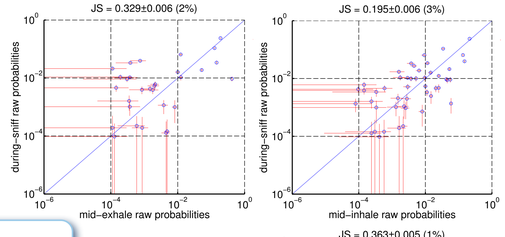
...yet mid-exhale and -inhale vocabularies are easily distinguished from...



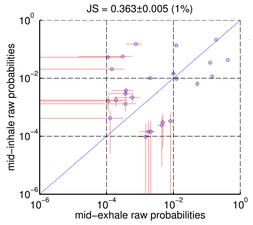
...between-sniff vocabulary...

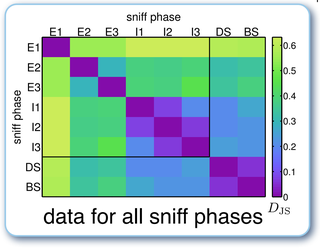


...during-sniff vocabulary...



...and each other.

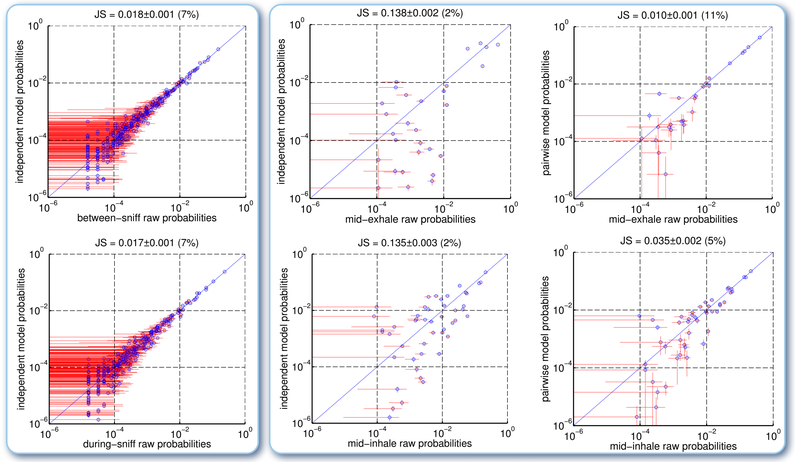




Rate and covariance analysis

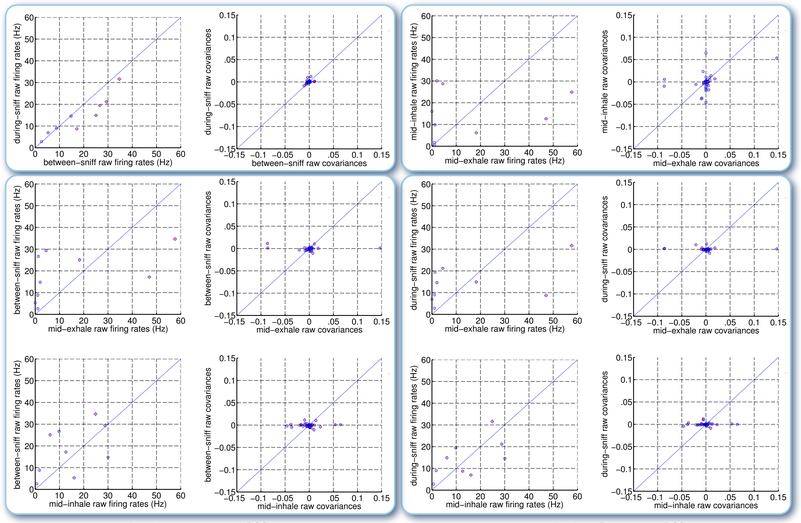
Between- and during-sniff activity well-characterized by firing rates alone...

...while mid-exhale and -inhale are poorly characterized by firing rates alone and much better-characterized by rates and covariances.

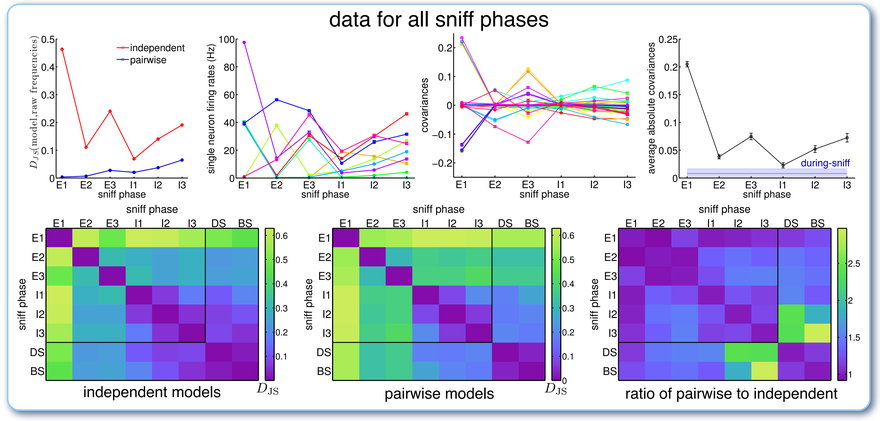


Between- and during-sniff rates and covariances similar...

...while mid-exhale and -inhale differ from each other...

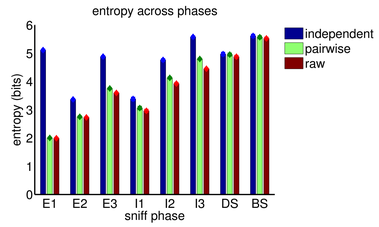


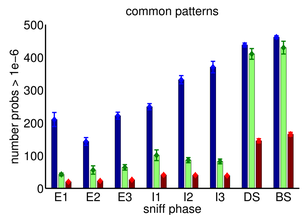
...between-sniff... **...and during-sniff.**



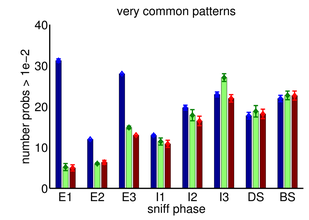
Entropy and unique pattern analysis

Each sniff phase is characterized by a lower-entropy vocabulary...

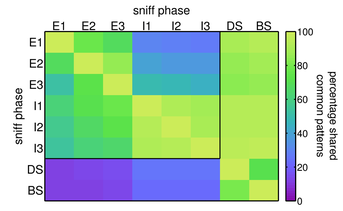


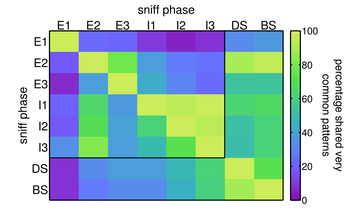


...featuring 25-50 common...



...and 5-20 very common patterns...





...~15-50% and ~30-85% of which are unique to each sniff phase.

Appendix: JS divergence and maximum-entropy models

$$D_{\mathrm{JS}}[P \mid Q] \equiv \frac{1}{2} D_{\mathrm{KL}}[P \mid M] + \frac{1}{2} D_{\mathrm{KL}}[Q \mid M] \quad \text{where} \quad M \equiv \frac{1}{2}(P+Q)$$

$$P^{(1)}[x_1, \ldots x_N] = \frac{1}{Z} \exp[\sum_{i=1}^{N} h_i x_i] \qquad P^{(2)}[x_1, \ldots x_N] = \frac{1}{Z} \exp[\sum_{i=1}^{N} h_i x_i + \sum_{i,j} J_{ij} x_i x_j]$$

Conclusions

- Olfactory bulb neural activity contains strong, behaviorally-locked structure which can be missed if behavioral coupling is ignored.
- Sniff phase might be inferred from local neural activity in the olfactory bulb without requiring an efference copy of the sniff motor command.

Future work

- Explicitly test whether sniff phase may be decoded using most probable patterns
- Check for temporal structure in between-sniff activity
- Check which results hold for odor-driven responses

References

data: Shusterman, R, Smear, MC, Koulakov, AA, & Rinberg, D. (2011). *Precise olfactory responses tile the sniff cycle.* Nature Neuroscience, 14(8), 1039–1044.

maximum-entropy models: Schneidman, E, Berry, MJ, Segev, R, & Bialek, W. (2006). *Weak pairwise correlations imply strongly correlated network states in a neural population.* Nature, 440(7087), 1007–1012.

Acknowledgements

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