Challenges in inferring breathing rhythms from olfactory bulb local field potentials

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Abstract

Odors convey useful navigational and episodic information, yet much of the chemical world remains inaccessible without active sampling through sniffing. To effectively interpret olfactory cues, the brain must unify odor-driven activity with respiratory cycles, making accurate respiratory measurements critical in understanding olfactory bulb (OB) dynamics. Previous studies have shown that behavioral signals are often present in primary sensory areas, and OB local field potentials (LFPs) have long been known to couple with respiration. Here we investigated whether OB LFPs can reliably recover the precise timing and frequency of respiration. Our results indicate that OB LFPs across multiple frequency bands align with respiratory cycles. Using time and frequency domain methods, we show that 2-12 Hz LFP oscillations effectively track respiratory frequency. However, a monotonic relationship between LFP-respiratory delay and sniffing frequency, which varies across animals, renders the recovery of precise respiratory events challenging. This work underscores the complex and individualized relationship between rodent respiration and OB LFPs, contributing to our understanding of how respiratory signals are represented in the OB.

Background

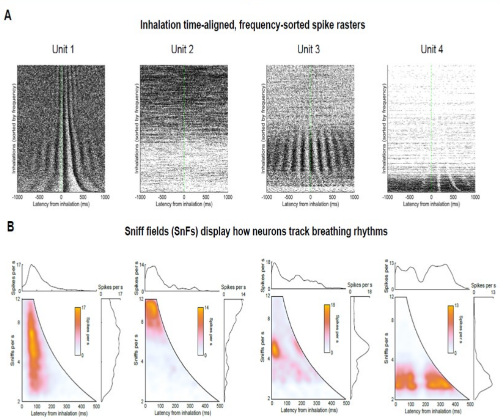


Figure 1: Single neurons track breathing rhythms. **A.** Spike raster of four single units simultaneously recorded with dots to indicate spike times relative to inhalation. **B.** Sniff field plots from the same four units reveals latency and sniff frequency tuning in the OB.

Experimental design

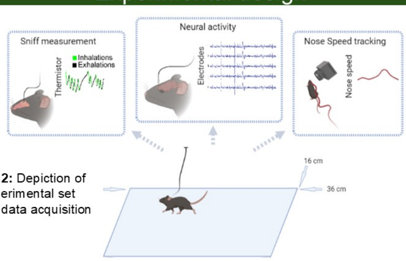


Figure 2: Depiction of the experimental set up and data acquisition

Raw signals

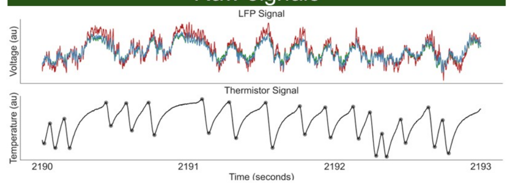
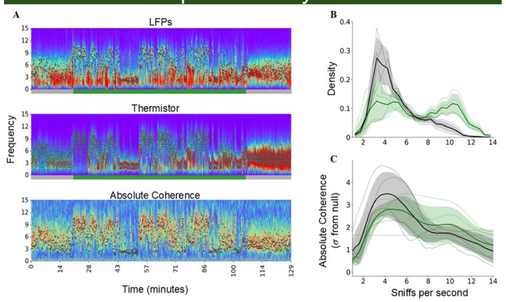


Figure 3: Local field potentials and respiration appear aligned in time and frequency.

Spectral analysis



$$S_w(f) = \frac{1}{K}\sum_{k=1}^{K}\left|\sum_t x_w(t)\cdot h_k(t)\cdot e^{-2\pi i f t}\right|^2$$

Figure 4: Spectral Analysis reveals coherence between LFPs and respiration. **A)** Spectrograms computed in 4s windows sliding in 400ms increments. Black scatter overlay represents sniff frequency. ***Top & Middle***) Power spectral density. ***Bottom***) Coherence. **B)** sniff frequency distribution. **C)** Coherence between LFPs and respiration as standard deviations from a null distribution. Dotted line represents significance threshold. Color shows head fixation in red and free movement in blue.

Time-domain visualizations

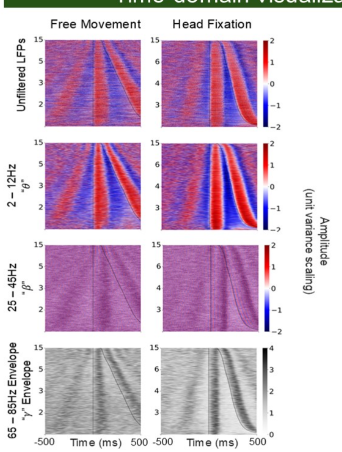


Figure 5: Time-domain visualizations reveals OB LFPs in multiple frequency bands are aligned to inhalation. Heatmaps show inhalation aligned LFP epochs stacked in the y-direction according to instantaneous sniffing frequency. Each row represents an LFP epoch with color to represents the amplitude of the unit variance scaled epochs

Time-domain analysis

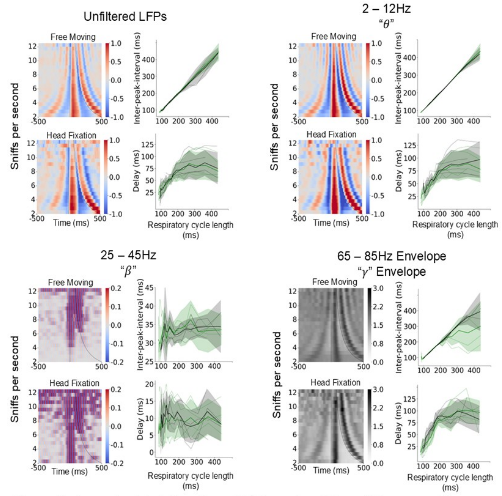


Figure 6: Averaging inhalation aligned LFP epochs within sniff frequency bins demonstrates timing relationships between LFPs and respiration. **Unfiltered LFPs** are linearly correlated with respiration by cycle length, and there is a monotonic relationship between LFP-respiratory delay and respiratory cycle length. **Theta** and **Gamma Envelope** oscillations show the similar time-domain characteristics as raw LFPs with respect to respiration. **Beta Band** oscillations aligned to inhalation have a cycle length and LFP-respiratory delay that is invariant to respiratory cycle length.

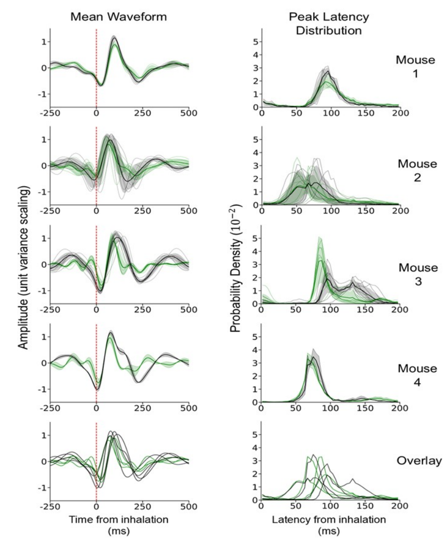


Figure 7: LFP-respiratory delay is not constant across sessions or mice.

Inferring sniffing from LFPs

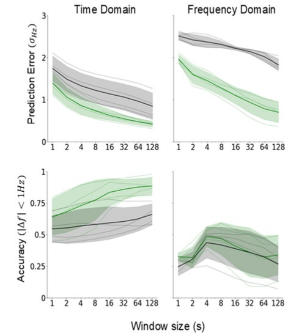


Figure 8: Respiratory frequency in sliding windows can be recovered from 2 – 12Hz LFPs. Time domain methods takes the mean reciprocal of inter-peak-intervals. Frequency domain methods finds the peak in the power spectrum.

Time Domain

$$f_w^1 := \frac{1}{N_w - 1}\sum_{n=1}^{N_w-1}\frac{1}{p_{n+1}-p_n}$$

Frequency Domain

$$f_w^2 := \arg\max_f S_w(f)$$

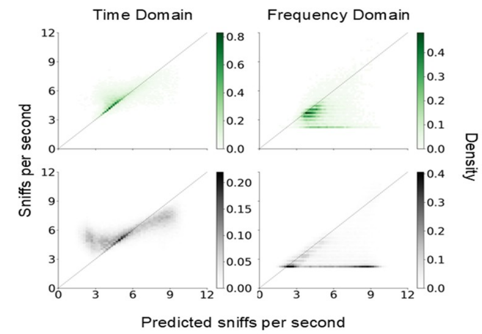


Figure 9: Heatmap shows the distribution of true vs predicted respiratory frequencies in 4 second sliding windows. 2-dimensional histogram was created with 50 bins.

Discussion

- Olfactory bulb local field potentials can be used to estimate the respiratory frequency of head fixed and freely moving mice
- Variable LFP-respiratory delay makes recovering respiratory events challenging.
- Peak finding in filtered LFPs leads to higher accuracy compared with powerful spectral estimates.
- LFP-respiratory description in rats (Kay et al., 2006) replicated here in mice

References

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