Arousal dynamics predict transitions in engagement state

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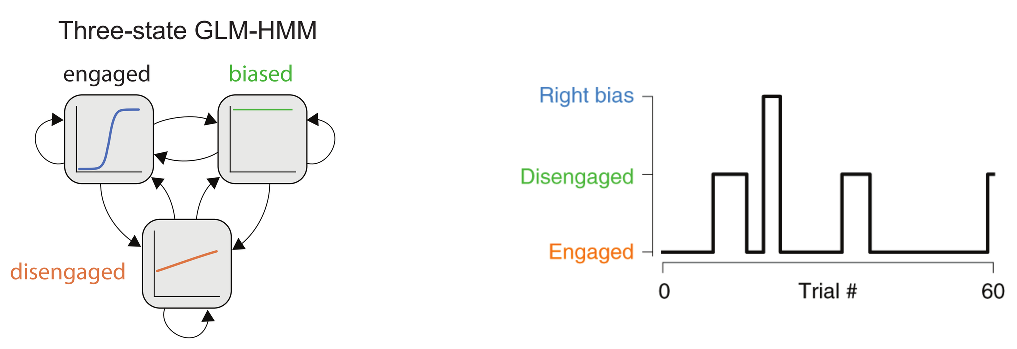
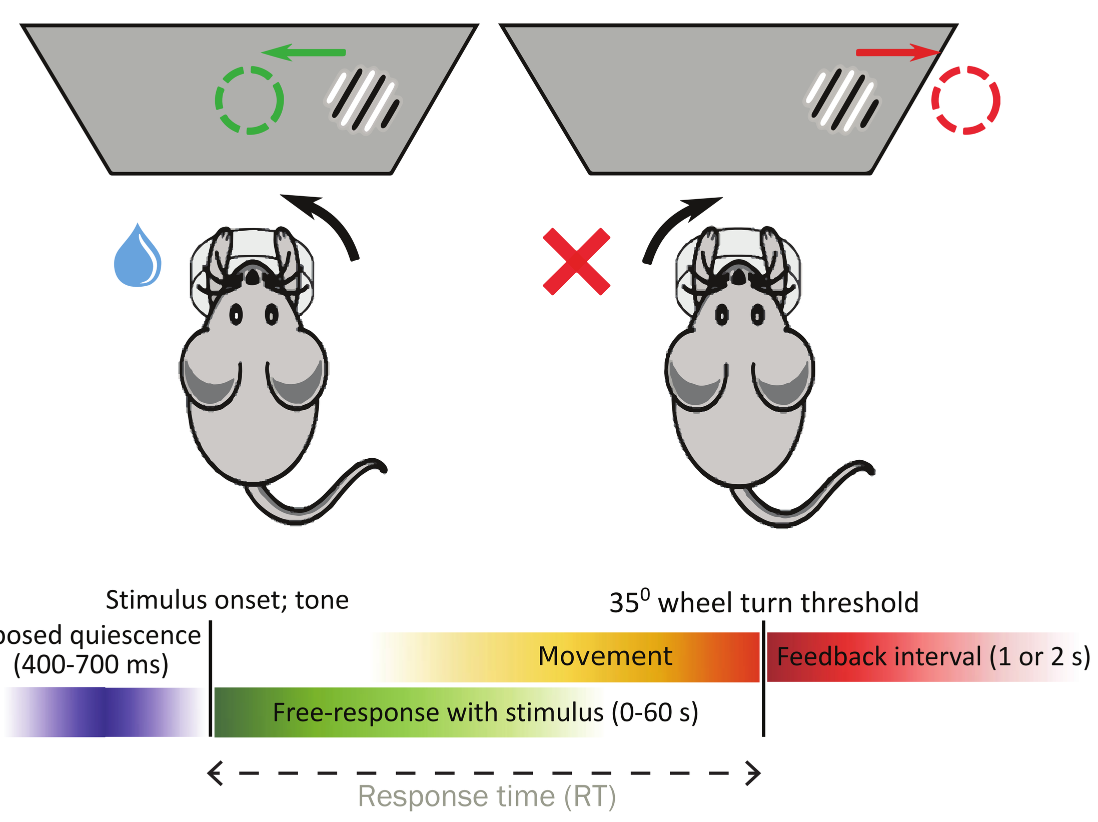
Introduction

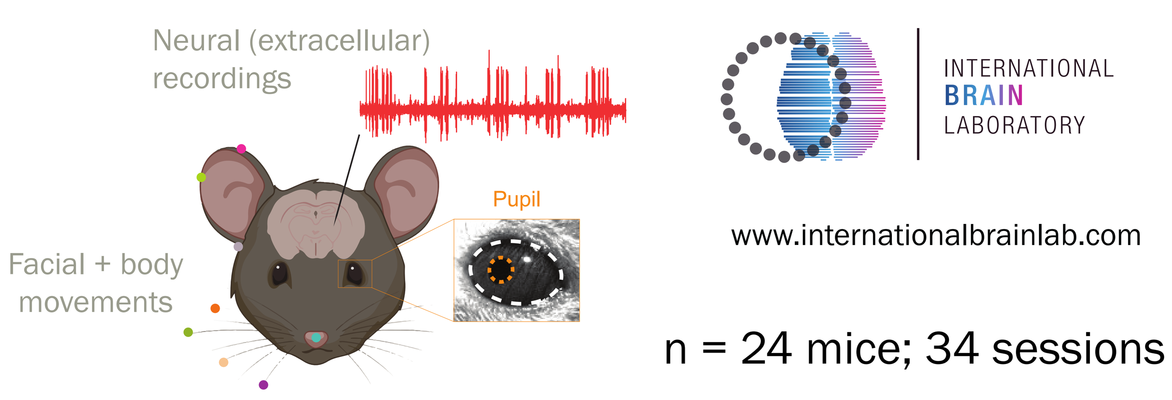
- When completing a task for a prolonged period, our ability to sustain attention fluctuates over time.
- In mice, disengaged behaviour has temporal autocorrelation (i.e., ‘disengagement states’), with animals showing attentional lapses clustered in time, rather than occurring randomly (Ashwood et al., 2019; Hulsey et al., 2023).



What neural and physiological processes trigger the transition into, and out of, (dis)engagement states?

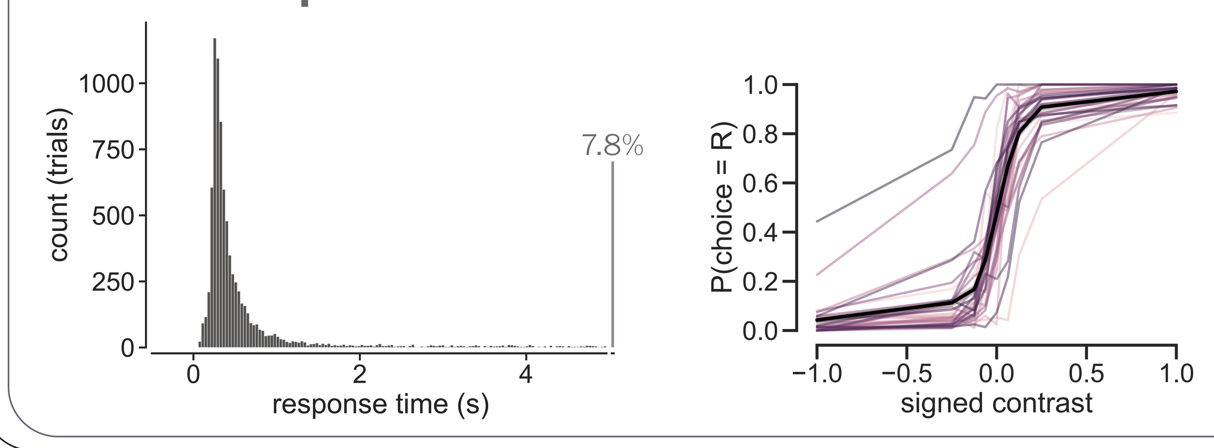
Task and data





n = 24 mice; 34 sessions

Behavioural performance



Conclusion

- Hidden Markov models applied to behavioural responses provide a method for identifying engaged and disengaged states.
- Engagement is associated with intermediate arousal.
- Variability of arousal changes as animals transition between states.
- A double-well model provides a possible mechanism through which arousal could affect engagement. Simulations and preliminary fits suggest that arousal could change the shape of the attractor landscape.

References

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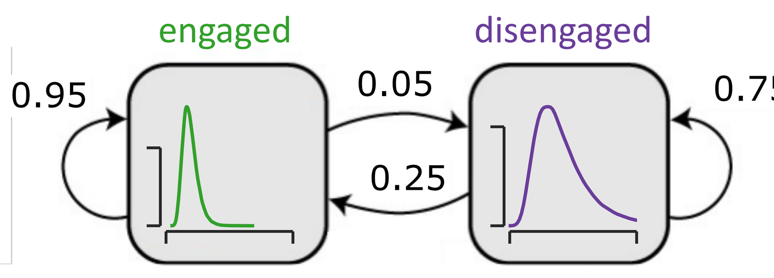
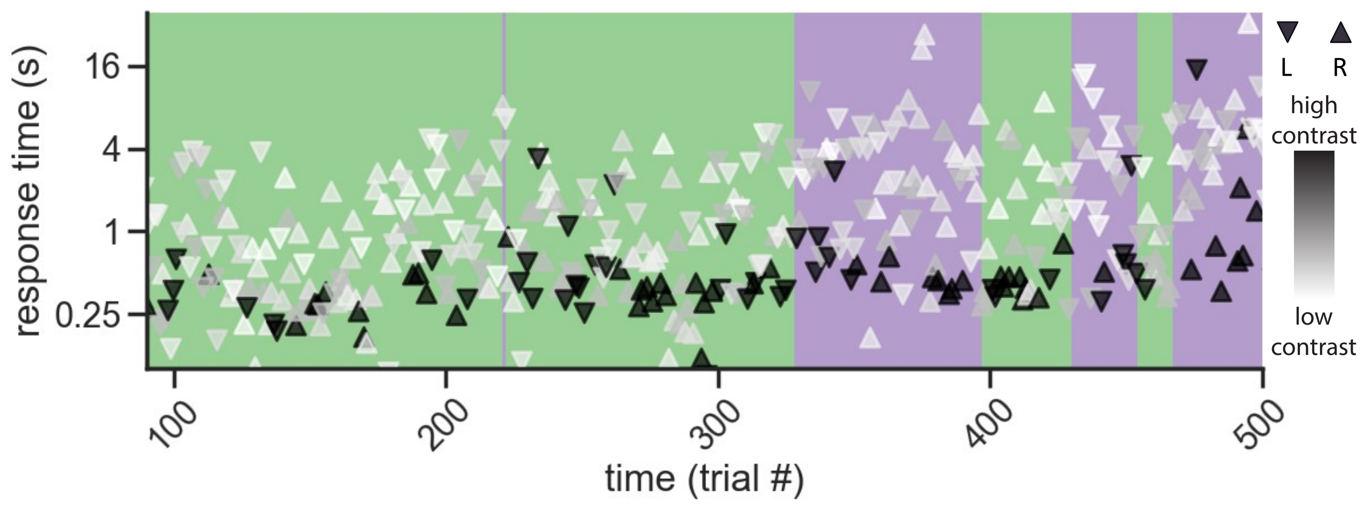
Identifying engagement state with HMMs



$$\mathbb{P}(state_t = k \mid state_{t-1} = j) = A_{jk}$$

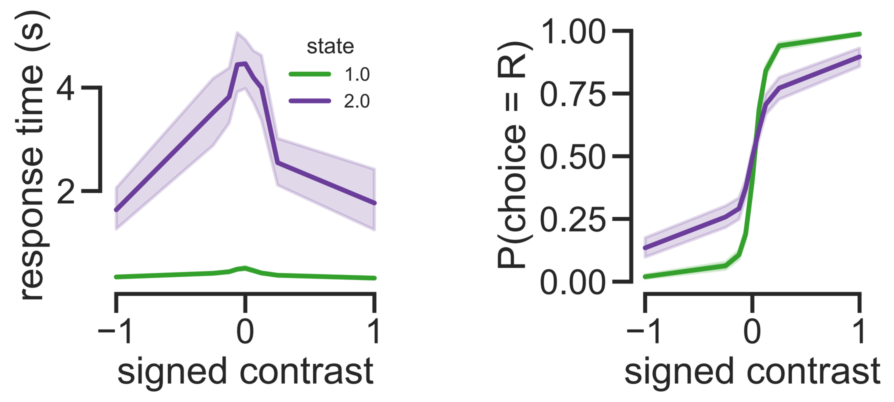
$$RT_t\,(x_t, state_t) = x_t w_{state} + \varepsilon_t$$



Model fitting

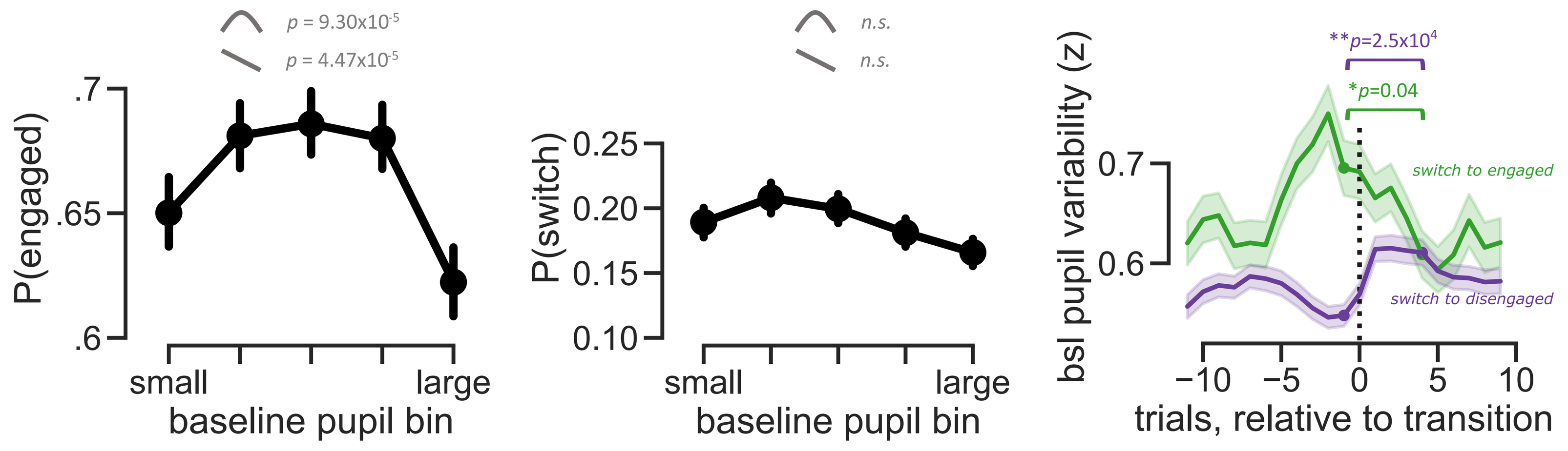
IOHMM toolbox (github.com/Mogeng/IOHMM)

expectation-maximisation algorithm



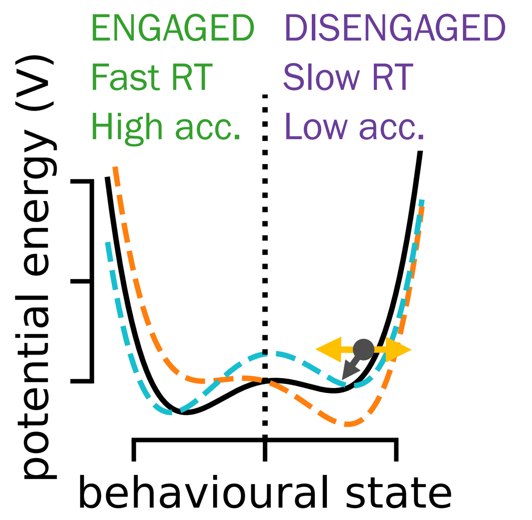
Across all sessions, one state is defined by a lower mean and variance of RT and better behavioural performance (engaged) than the other (disengaged).

Intermediate baseline pupil size is associated with engagement



Pupil variability decreases as animals enter the engaged state and increases as they enter the disengaged state (Hulsey et al., 2024).

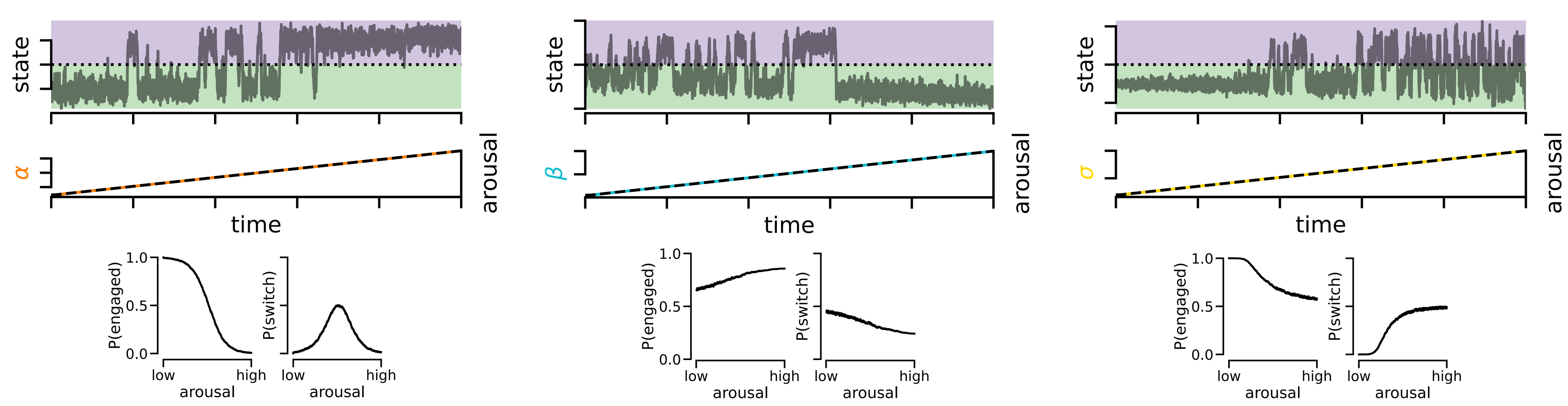
How could arousal control engagement state?



energy landscape: $V(x) = \frac{1}{4}x^4 - \underbrace{\beta}_{\text{boundary height}} x^2 - \underbrace{\alpha}_{\text{landscape tilt}} x$

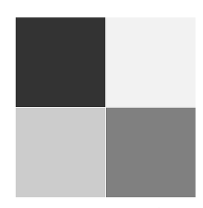
particle motion: $dx = \underbrace{\frac{dV}{dx}dt}_{\text{drift}} + \underbrace{\sigma}_{\text{diffusion}} dw$

We apply a phase transition model to investigate possible mechanisms for how arousal could affect state occupancy and transitions.



fitting across-sessions using HMM transition matrices

from HMM transition matrix

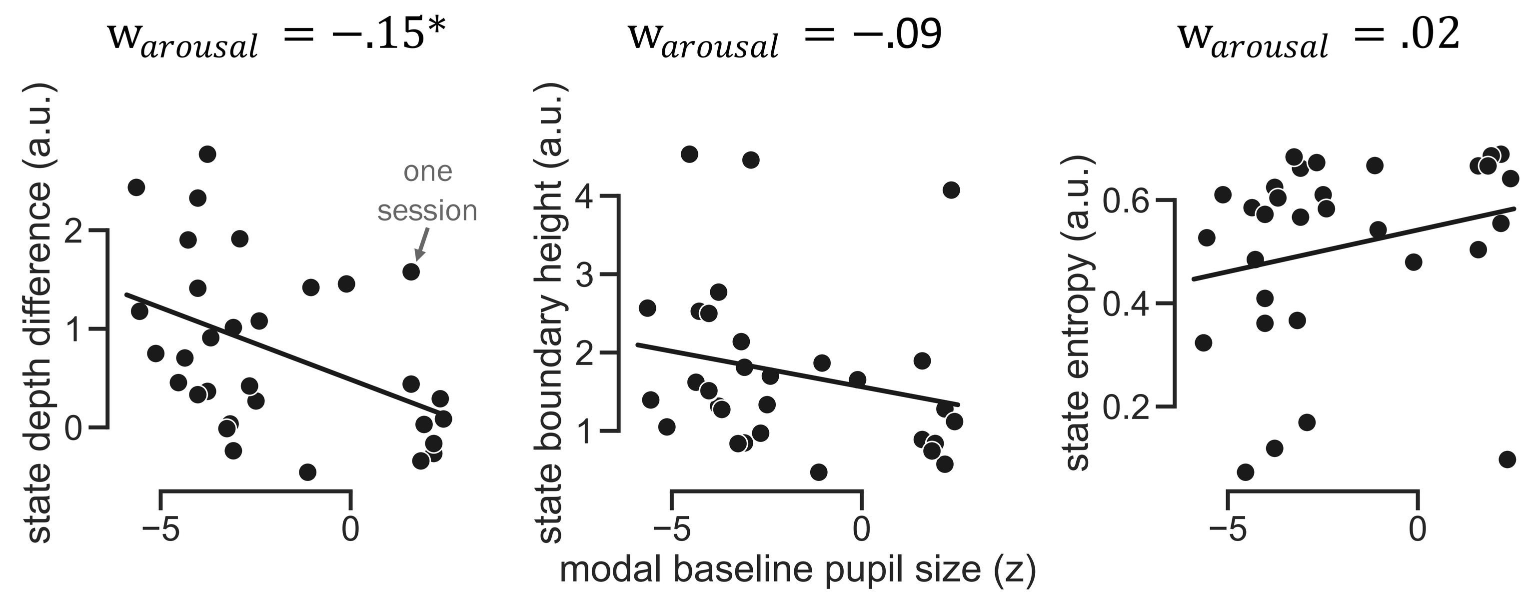


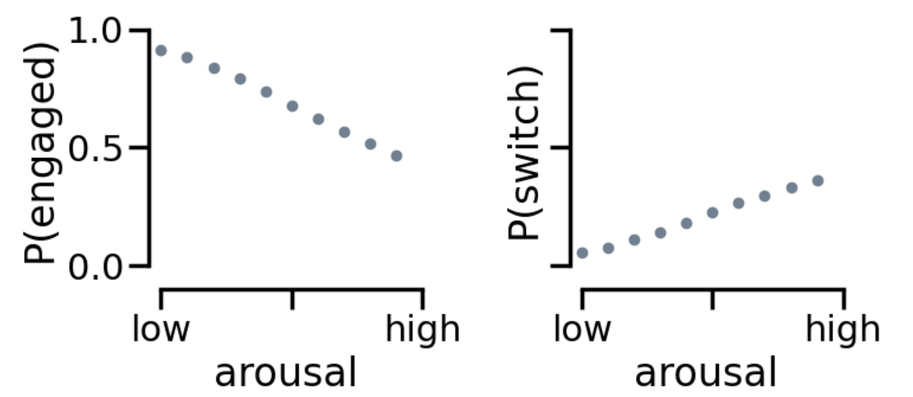
compute

state depth difference $\propto \mathbb{E}(\alpha)$

state boundary height $\propto \mathbb{E}(\beta)$

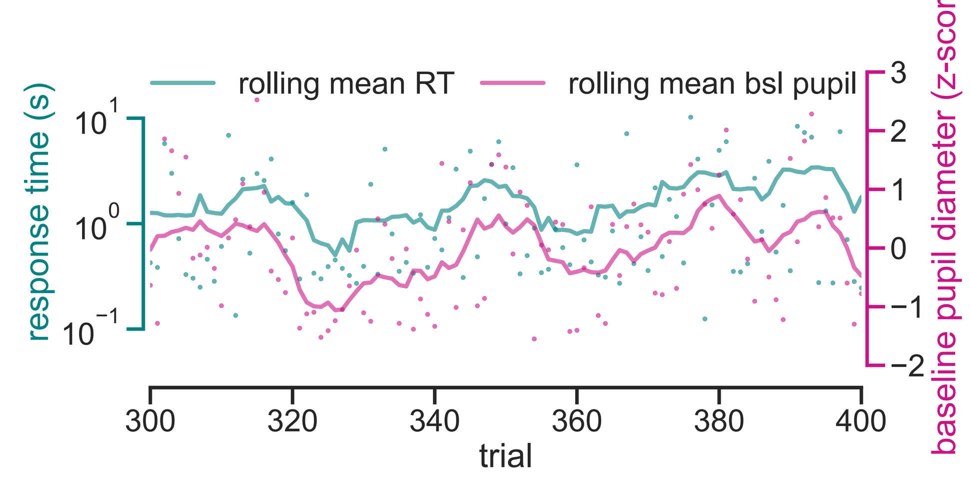
state entropy $\propto \mathbb{E}(\sigma)$





Prelimary model fitting suggests that arousal acts by changing the shape of the attractor landscape rather than the influence of noise in the system. However, this linear combination of parameters does not capture the observed relationship between arousal and state.

fitting to within-session timecourses?



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