A conserved brain state linking neural and hemodynamic dynamics to spontaneous movement across species

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Introduction

The brain performs complex information processing across a range of temporal and spatial scales [1]. Fast neural dynamics can be measured using EEG or Ca^{2+} imaging, while slower BOLD dynamics can be measured using fMRI. These modalities provide complementary insights into brain activity [2].

Both types of dynamics exhibit recurring patterns of brain activity, which can be characterized as distinct brain states [3].

But it is unclear how neural and BOLD states are linked.

Open question:

- Do neural-state and BOLD-state dynamics correspond spatiotemporally?
- Are such correspondences conserved across modalities and species?

We utilize **simultaneous neural-fMRI** datasets to investigate association between states from different modalities.

Datasets

	SKKU (human) [4]	UMD (human)	Mouse Ca^{2+}-fMRI
Subjects	22 healthy adults	12 healthy adults	15 mice — GLIA (N=6), SLC/excitatory (N=9)
Model	—	—	Adult transgenic mice, cell-type-specific GCaMP
Anesthesia	Awake (eyes open)	Awake (eyes open)	Low-dose isoflurane
Scan duration	6 min 20 s	8 min	10 min/run, 2–4 runs/session, 3 sessions/mouse
fMRI field strength	3T	3T	11.7T
TR	2 s	2.52 s	1 s
Neural signal	64-channel EEG	64-channel EEG	Wide-field Ca^{2+} imaging; 60 cortical ROIs

Methods

We applied **Hidden Markov Models** [5] separately to band-limited neural signals (δ,θ,α,β) and to BOLD signals in these datasets, followed by **co-occurrence and coupling brain-state analysis framework**, applied across modalities and species, that:

- Detects neural state co-occurring interval across frequency bands
- Quantifies how frequently the co-occurrence is coupled with specific fMRI state
- Examines significance of the coupling through circular shift permutation testing

Conclusion

- **Selective, reproducible neural state cross-frequency co-occurrence:** replicated across two independent human EEG-fMRI datasets and the mouse Ca^{2+}-fMRI dataset.
- **Consistent BOLD signature:** the coupled BOLD state shows deactivation of control (cont) network.
- **Link to spontaneous movement:** co-occurrence intervals overlap peaks in framewise displacement in some but not all subjects.

References

1. Perdikis et al. (2011). Time Scale Hierarchies in the Functional Organization of Complex Behaviors. *PLOS Computational Biology*

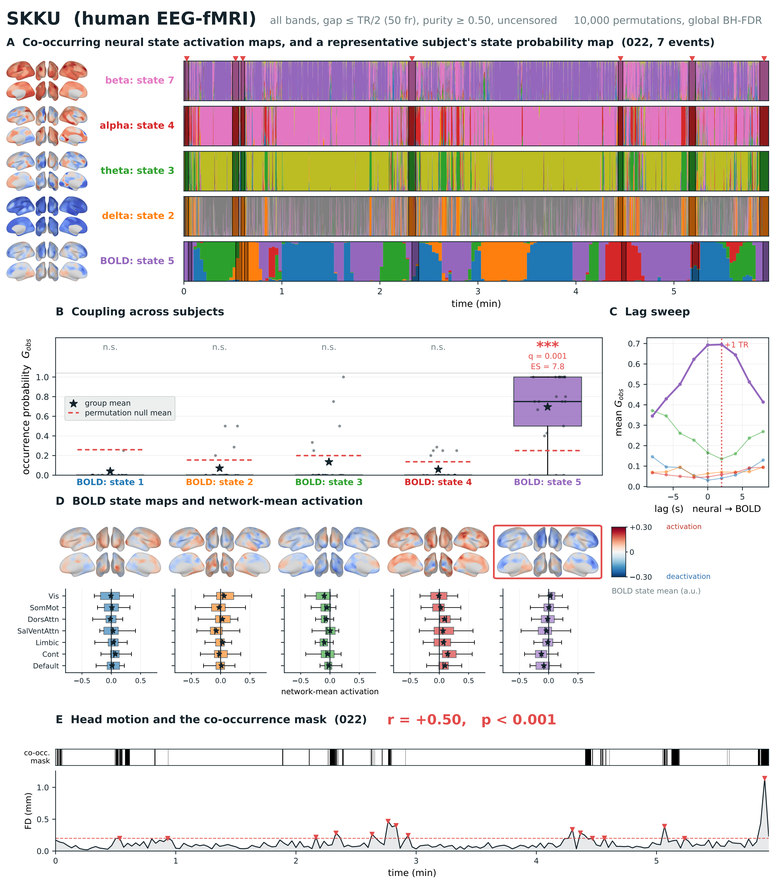
2. Chang & Chen (2021). Multimodal EEG-fMRI: Advancing insight into large-scale human brain dynamics. *Current Opinion in Biomedical Engineering*

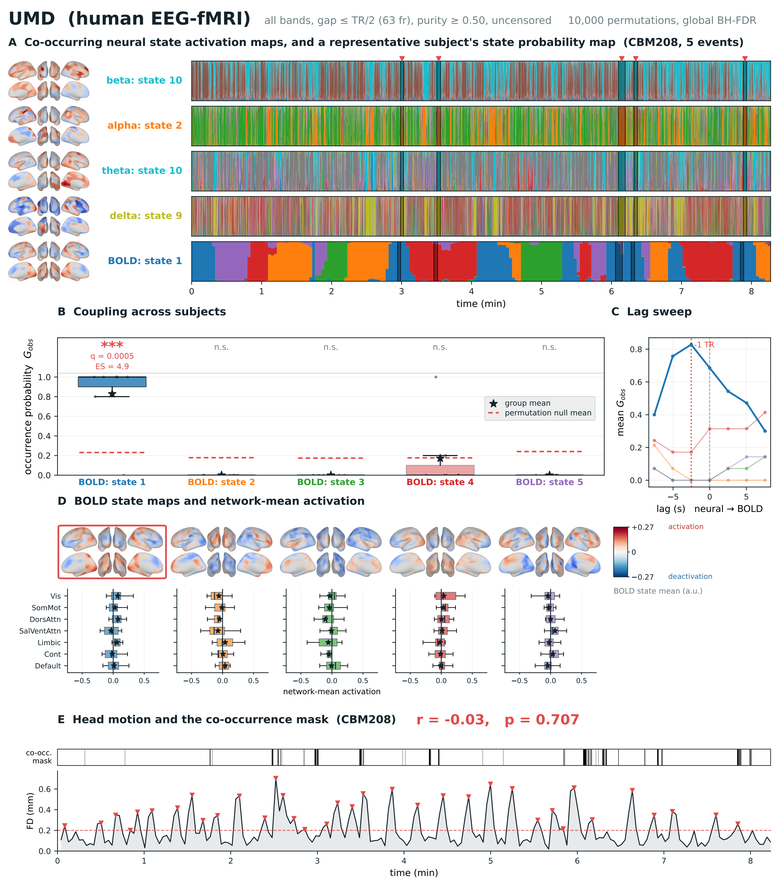
3. Deco et al. (2011). Emerging concepts for the dynamical organization of resting-state activity in the brain. *Nature Reviews Neuroscience*

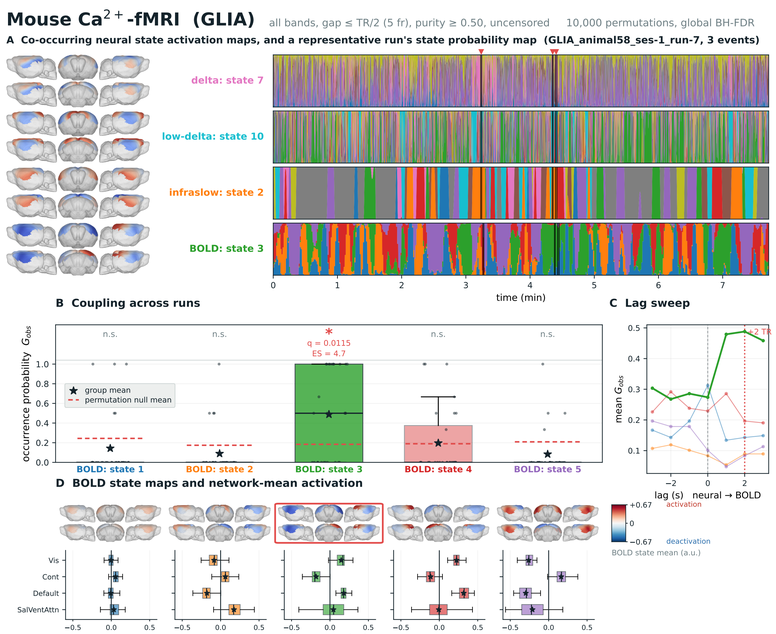
4. Cha et al. (2026). Sustained Attention Task (gradCPT) Dataset using simultaneous EEG-fMRI and DTI. *Scientific Data*

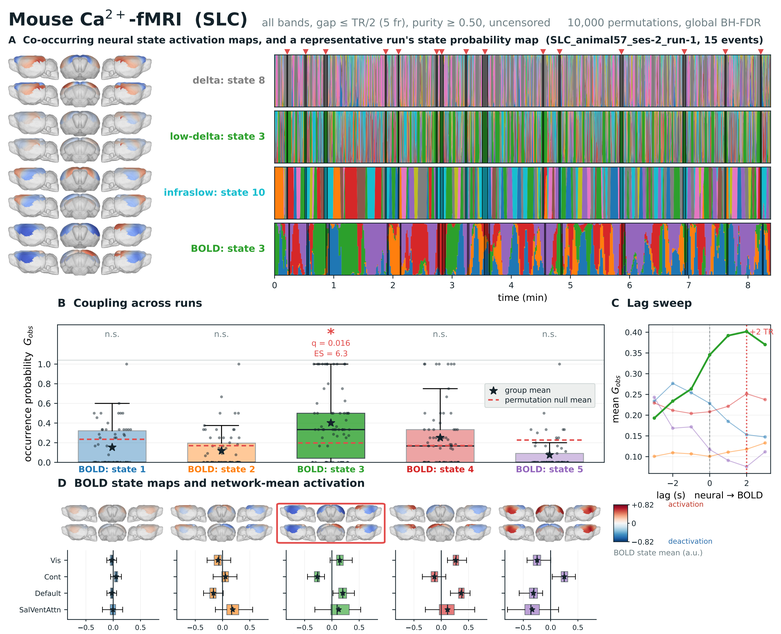
5. Vidaurre et al. (2016). Spectrally resolved fast transient brain states in electrophysiological data. *NeuroImage*.

Results









Acknowledgement

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