

# Functional interactions in human cortex during sleep and wake

Annabelle Tao<sup>1,2</sup>, Jerry Wang<sup>2,3</sup>, Gabriel Kreiman<sup>2,3</sup>

<sup>1</sup>Harvard University, Cambridge MA; <sup>2</sup>Center for Brains, Minds, and Machines, Cambridge, MA; <sup>3</sup>Harvard Medical School, Boston MA



**Introduction.** We are regularly and naturally unconscious during non-dream sleep, so understanding the neural differences between sleep and wake is key to understanding the neural correlates of consciousness.

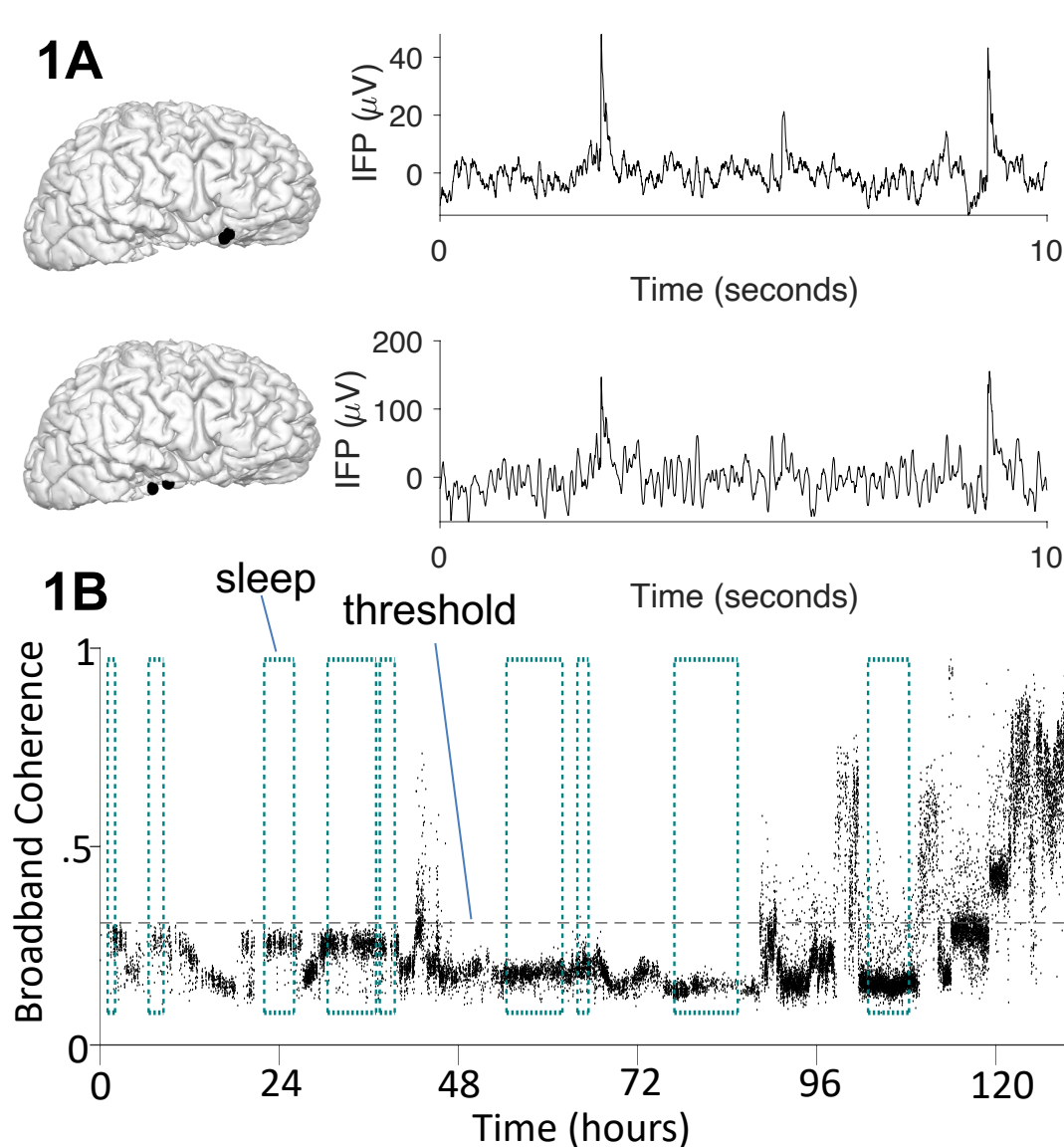
**Methods & Results:** We evaluated functional interactions between brain regions in intracranial electroencephalography (iEEG) by calculating the coherence between pairs of bipolar electrodes over 10-second windows. The coherence between electrodes  $a$  and  $b$  is defined as:

$$C_{ab}(f) = \frac{|G_{ab}(f)|}{\sqrt{G_{aa}(f)G_{bb}(f)}}$$

where  $G_{aa}$  and  $G_{bb}$  are the auto-spectral densities and  $G_{ab}$  is the cross-spectral density. For details, see Wang 2018. We compared coherence between sleep and wake states.

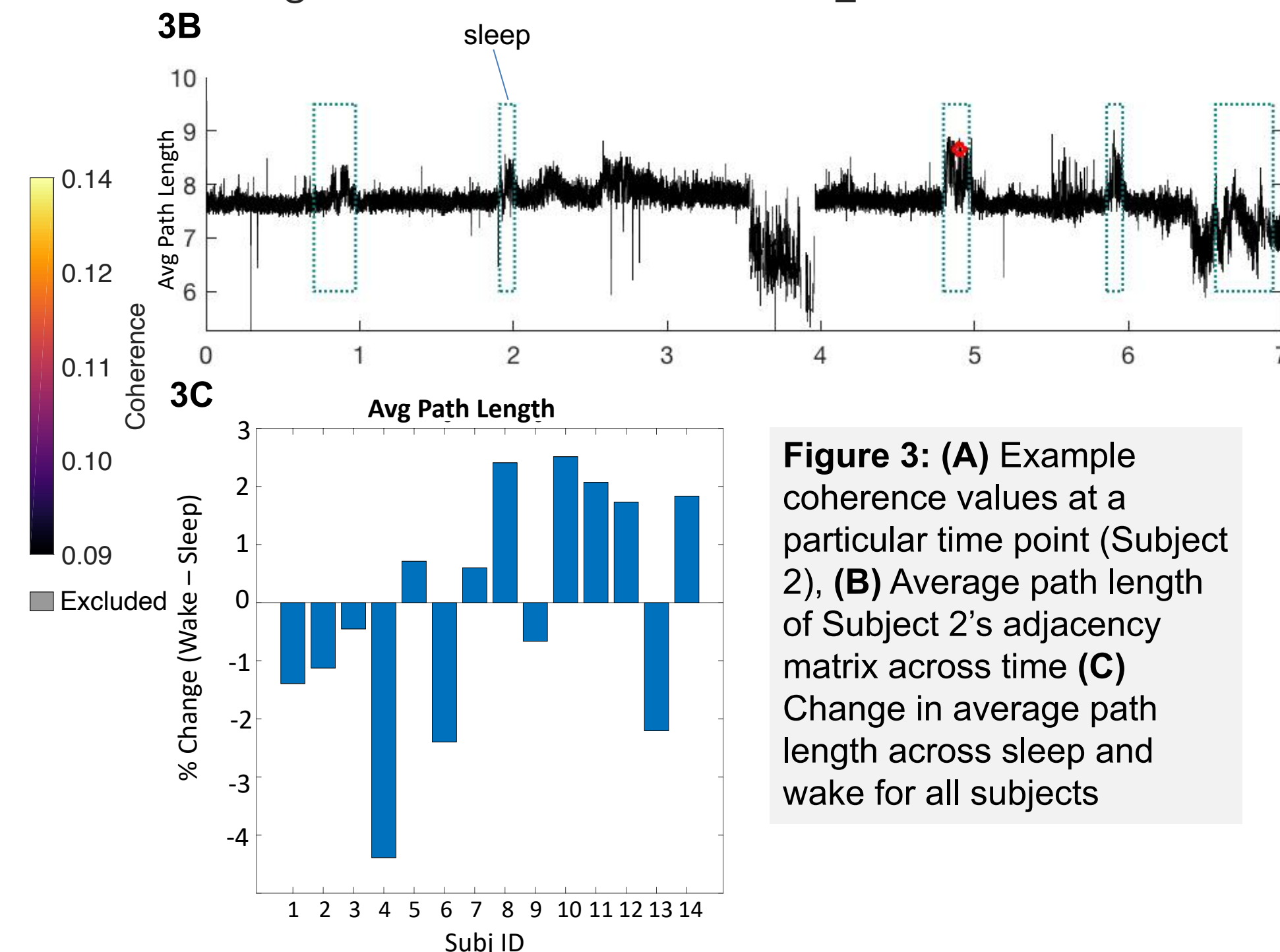
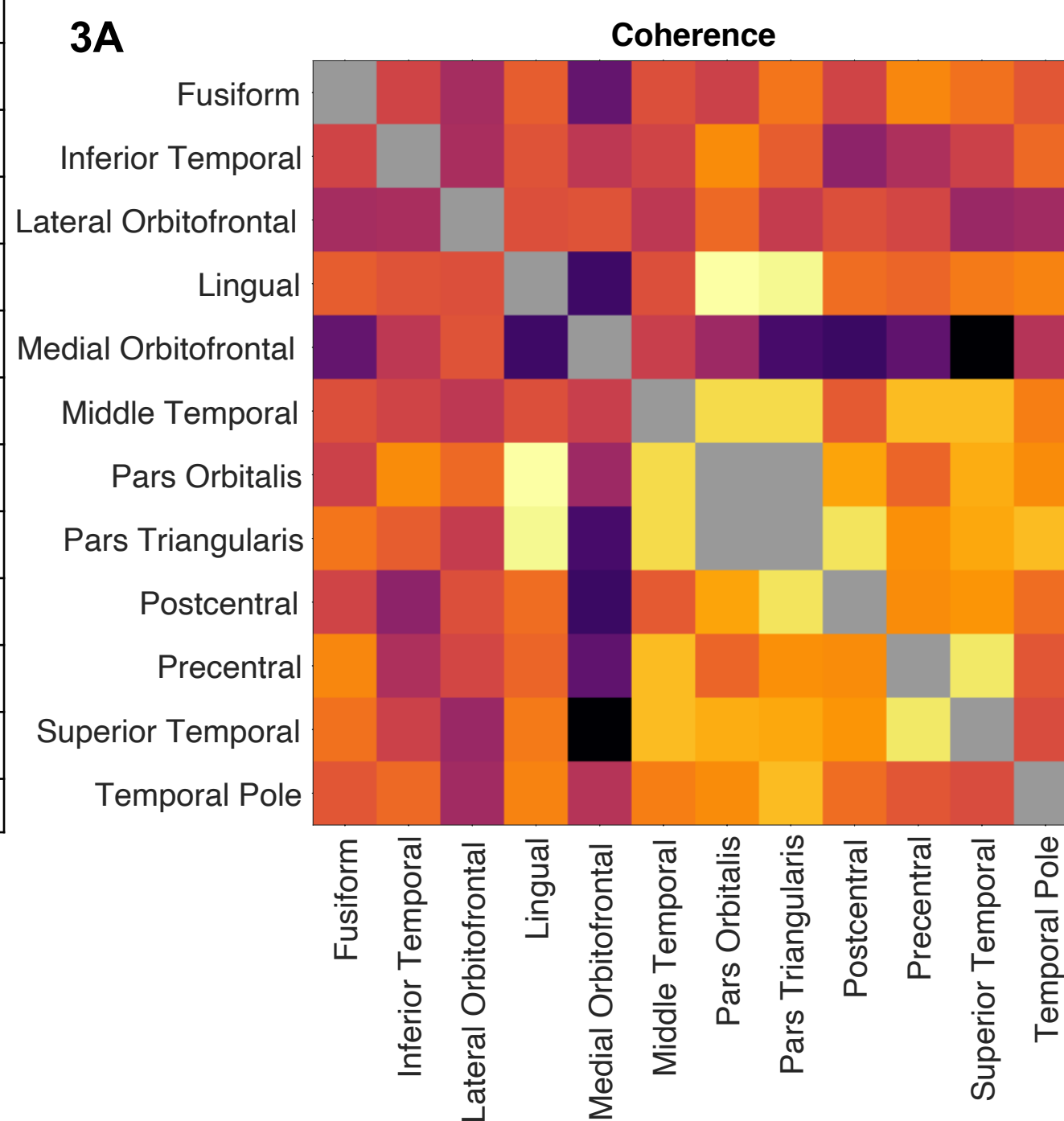
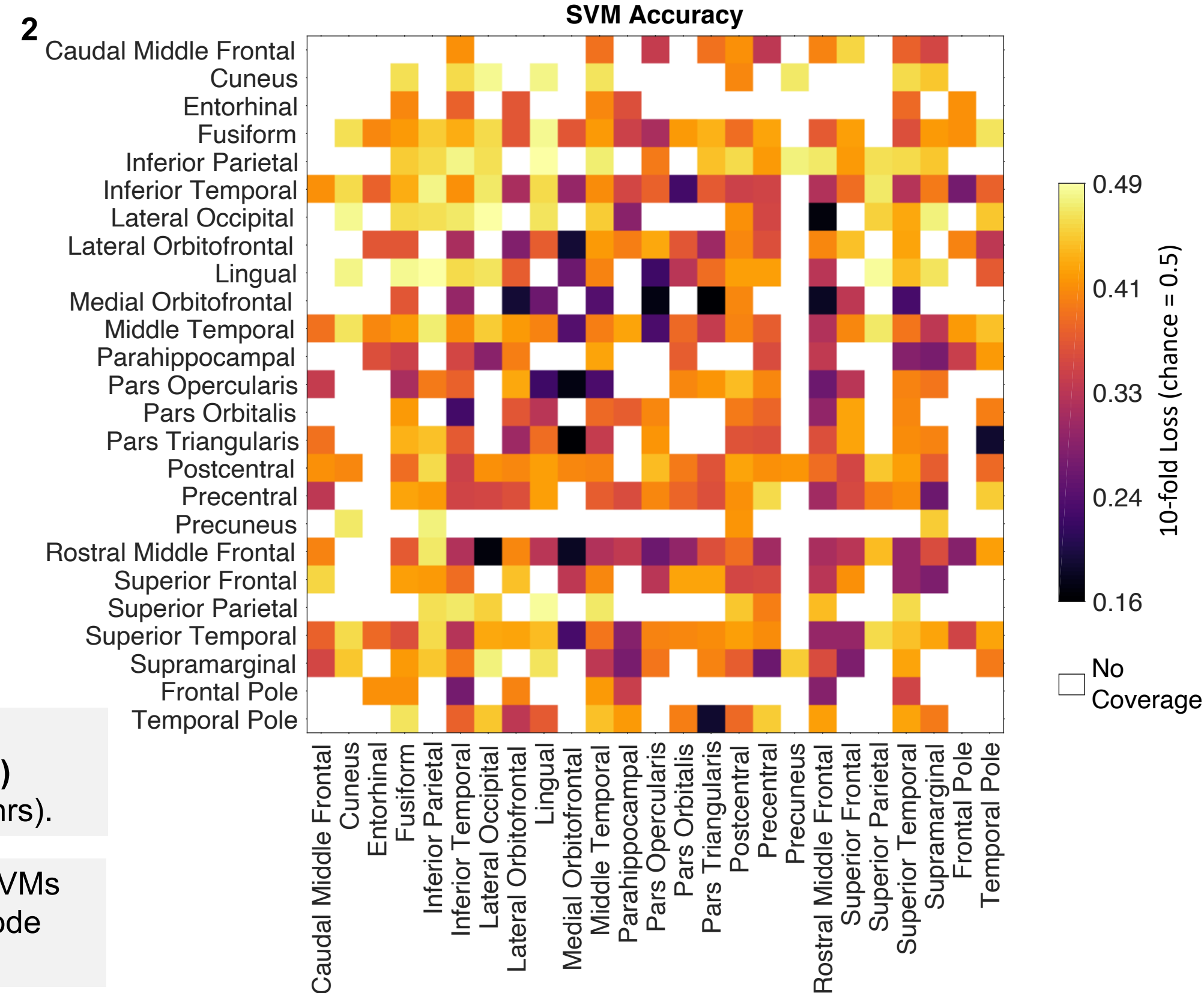
Subject ID	% sleep	Hours of data	10-fold Loss % (chance = 50)
1	43.4	84	5.00
2	14.5	168	5.75
3	32.6	134	9.55
4	23.0	49	7.87
5	43.0	90	6.54
6	39.2	121	7.88
7	27.8	64	5.93
8	25.3	93	7.52
9	45.2	110	6.92
10	46.9	60	4.17
11	28.3	116	6.26
12	48.7	39	5.27
13	30.7	125	9.96
14	30.9	110	4.85
Average	34.2 (10.3)	97.4 (36.0)	5.38 (0.53)

**Table 1:** Each 30-minute segment of the patient video was manually annotated as either sleep or wake. Sleep was defined as a continuous period without movement and with eyes closed. 1,363 hours were annotated in total, with 445 hours (32.7%) of sleep. 50% of subjects were female, with average age of 24.4 (SD = 12.7). The fourth column reports 10-fold cross-validation losses for SVMs trained on the annotated iEEG data.



**Figure 1 (above):** (A) Example intracranial field potentials for two bipolar electrodes (Subject 3). (B) Coherence values for Subject 3's entire stay (134 hrs).

**Figure 2 (right):** 10-fold cross-validation loss for SVMs trained on coherence values of each bipolar electrode pair ( $n = 20,017$ , mean .40, SD .12, chance = .5)



**Figure 3:** (A) Example coherence values at a particular time point (Subject 2), (B) Average path length of Subject 2's adjacency matrix across time (C) Change in average path length across sleep and wake for all subjects

**Conclusions:** The preliminary results suggest that we can: (1) automatically classify sleep versus wake with a high level of accuracy in ECoG data, (2) distinguish between sleep and wake based on pairwise interactions between brain areas, and (3) characterize sleep and wake according to changes in network properties

**Further questions?** [a\\_tao@college.harvard.edu](mailto:a_tao@college.harvard.edu); **Conflicts of Interests:** None; **Funding Sources:** Harvard College Research Program, NSF, NIH