Cerebrospinal fluid flow closely tracks behavioral performance during an attention task

Zinong Yang[1,5], Stephanie D. Williams[2,5], Ewa Beldzik[5,6], Stephanie Anakwe[5], Emilia Schimmelpfennig[3], Laura D. Lewis[4,5,6*]

1. Graduate Program for Neuroscience, Boston University, Boston, MA, USA, 2. Psychological & Brain Sciences., Boston University, Boston, MA, USA, 3. Department of Biomedical Engineering, Boston University, Boston, MA, USA. 4. Institute for Medical Engineering and Science, Massachusetts Institute of Technology, Cambridge, MA, USA. 5. Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, USA. 6. Athinoula A. Martinos Center for Biomedical Imaging, Department of Radiology, Massachusetts General Hospital, Boston MA, USA

Introduction

- Sleep plays a fundamental role in maintaining brain health and preserving cognitive performance. Sleep deprivation (SD) reliably induces attentional failures despite this cost, suggesting that they reflect an unavoidable need of the brain for sleep[4,5].

However, the mechanisms that govern these sleep-privation induced attentional failures are not yet well understood.

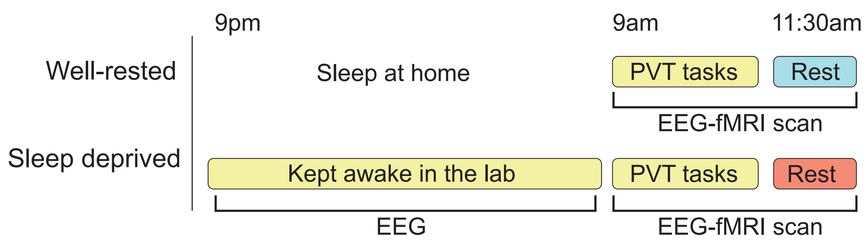
- Acute SD has widespread effects on both local and global aspects of neurophysiology, and these are correlated with attentional deficits[6,7]. Attentional lapses after SD are also associated with altered fMRI dynamics, changes in oscillatory and aperiodic electrophysiological activity, as well as spontaneous fluctuations in pupil diameter.

What prompts the brain to generate these spontaneous drops in arousal state after sleep deprivation?

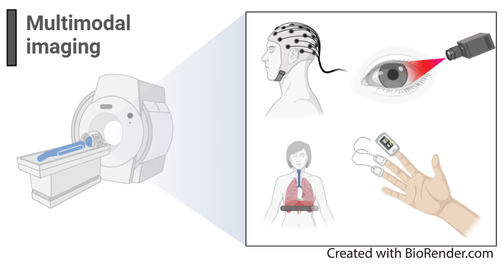
- SD might change the cerebrospinal fluid (CSF) dynamics. One night of SD can elevate levels of amyloid in the brain, and tracers infused into the human brain are cleared more rapidly during sleep than during wakefulness[1].

In the current work, we aim to investigate whether sleep deprivation induces sleep-like spontaneous activity at both the global cortical level and in brain fluid dynamics.

Experimental Setup

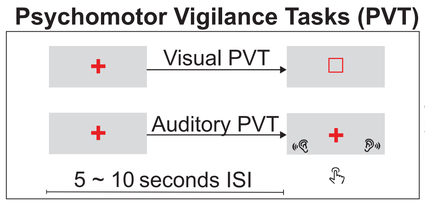


- 26 healthy participants age 19 to 40.
- Visit A: well rested Visit B: 24 hours total sleep deprived
  Order of A and B is counterbalanced



- T1 weighted，4 task fMRIs-EEG and 1 resting state fMRI-EEG (TR = 378ms, SMS factor 8, 2.5 mm isotropic voxel)
- Physiology recordings include respiration, pulse oximetry, ECG, and Eyetracking

Psychomotor Vigilance Tasks (PVT)



Subjects are instructed to press a button as fast as possible when the fixation cross changes into a square for the visual PVT, and when they hear the beep for the auditory PVT

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Conclusion

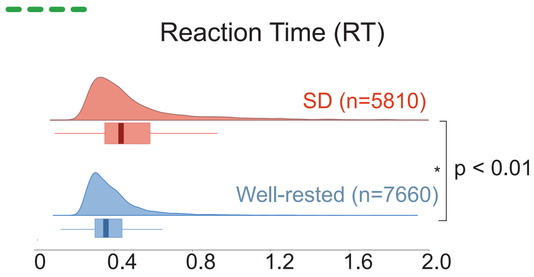
- After sleep deprivation, sleep-like pulsatile CSF flow intrudes into the awake state
- CSF flow is locked to attentional failures: ventricular CSF is pushed downwards at the onset of attentional failures, and flows back upwards when attention recovers
- Each CSF inflow event is tightly orchestrated by a series of brain-body changes including broadband neuronal spectral shifts, pupil constriction, and systemic physiological signatures, pointing to a highly coupled system of fluid dynamics and neuromodulatory state during sleep-deprived wakefulness.

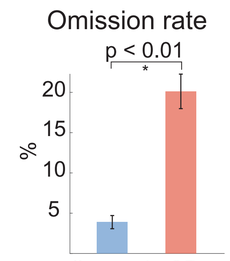
Contact: ziy027@mit.edu

Result

SD leads attentional deficits

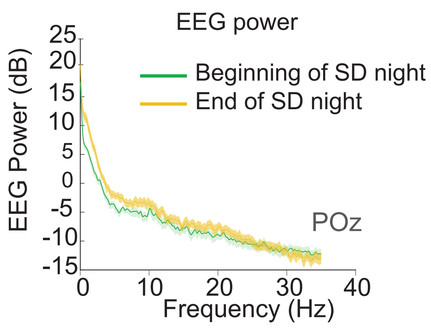
- Sleep deprivation significantly increases the mean reaction time from PVT and omission probability.

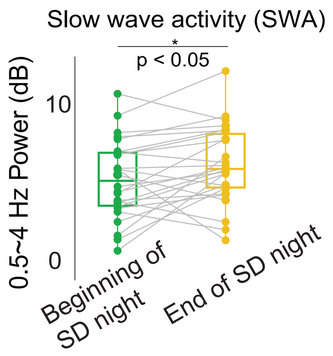


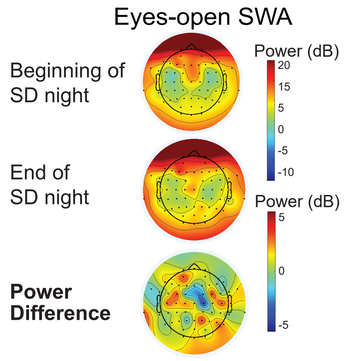


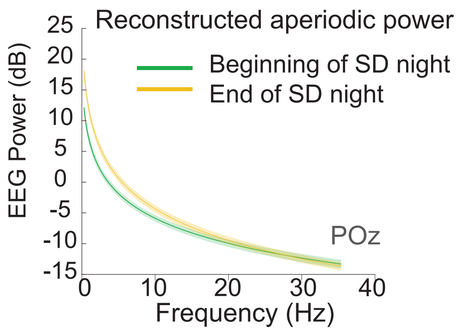
SD leads to EEG spectral shifts during resting wakefulness

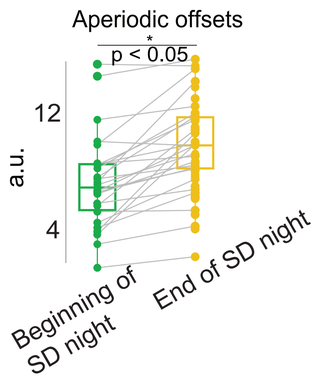
- EEG delta frequency power, a well-recognized indicator of sleep pressure, increases with time spent awake.
- EEG aperiodic activity, thought to be linked to excitatory-inhibitory balance, also changes with time spent awake. Suggesting that sleep deprivation decreases cortical excitability.

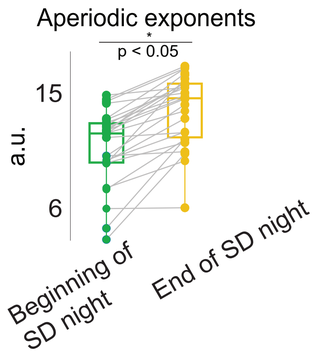






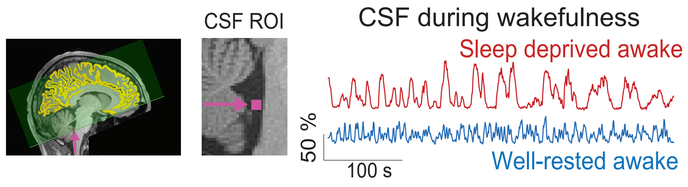


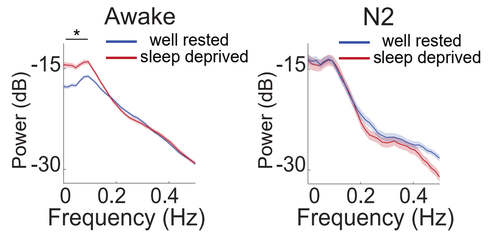


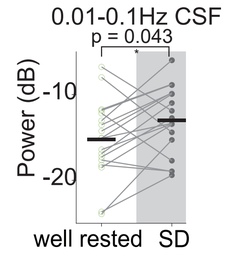


SD causes sleep-like pulsatile CSF flow to intrude into wakefulness

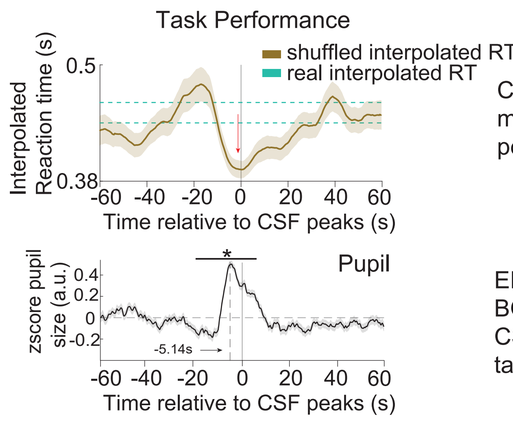
- CSF inflow signal during well-rested wakefulness exhibited a small-amplitude rhythm synchronized to respiration.
- In contrast, we found a 4.7 dB increase in the CSF signal peaking at 0.04 Hz during wakefulness after SD.



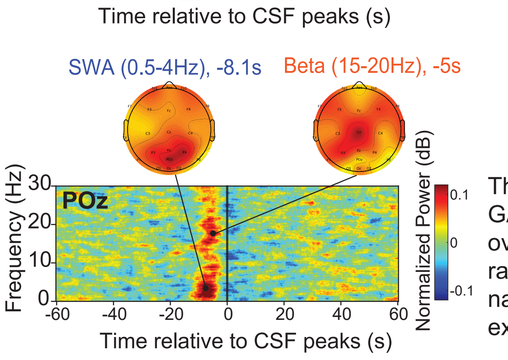




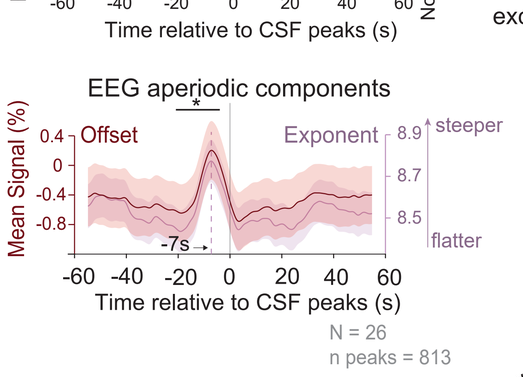
CSF inflow events during sleep-deprived wakefulness are tightly organized in a series of brain-and-body changes



Changes in task performance locked to CSF peaks

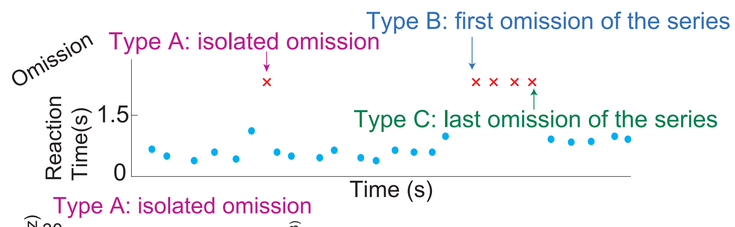


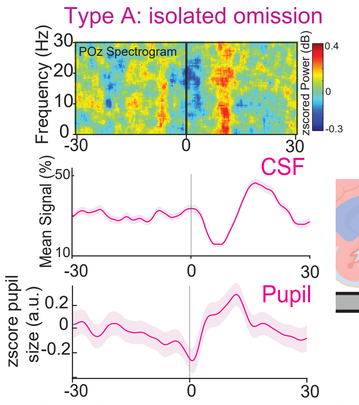
EEG, pupil and cortical BOLD activity all link to CSF dynamics during tasks.



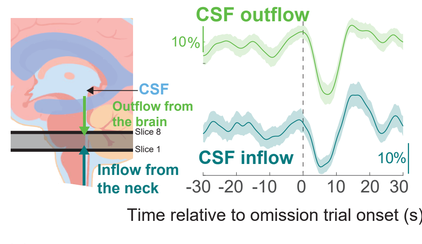
The net increase of GABA contribute to the overall decrease of E/I ratio, pointing to a dominance of inhibition over excitation.

CSF pulsatile flow is differentially modulated by loss and recovery of attention





Additional experiment showed that CSF outflow was locked to attention failures.



- All three types of omissions were accompanied by changes in EEG SWA and beta (15~20Hz) frequency power.
- The pupil dilation/constriction also showed significant correlation with CSF.