



Sleep spindles and sleep consciousness

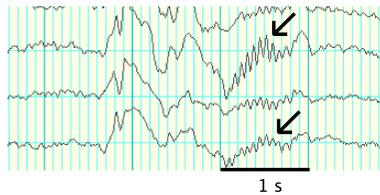
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Background

Conscious experience during sleep, also known as dreaming, is a ubiquitous phenomenon that is incompletely understood. Many theories of dreaming emphasize a distinction between rapid-eye-movement (REM) sleep and non-REM sleep. However, reports of conscious experience can be elicited upon awakening from any stage of sleep. We seek to understand the neural substrates of conscious experience during non-REM sleep.



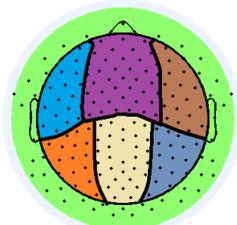
Sleep spindles are fusiform, 11–15 Hz oscillations characteristic of non-REM sleep. They are generated by reciprocal interactions between inhibitory thalamic reticular neurons and bursting thalamocortical relay neurons. The highly stereotyped, synchronized neural activity underlying sleep spindles implies a reduced array of potential thalamocortical firing patterns.¹ Therefore, we hypothesized that sleep spindles would be associated with reduced reports of consciousness during sleep.

We also collected subjective reports of features of the conscious experience, including richness and length of the experience. We predicted that sleep spindle activity would correlate with reduced levels of these subjective reports.

Finally, as a proof of principle, we applied multivariate pattern analysis to the electroencephalogram in order to predict presence of conscious experience from the power density in the 11–15 Hz frequency band.

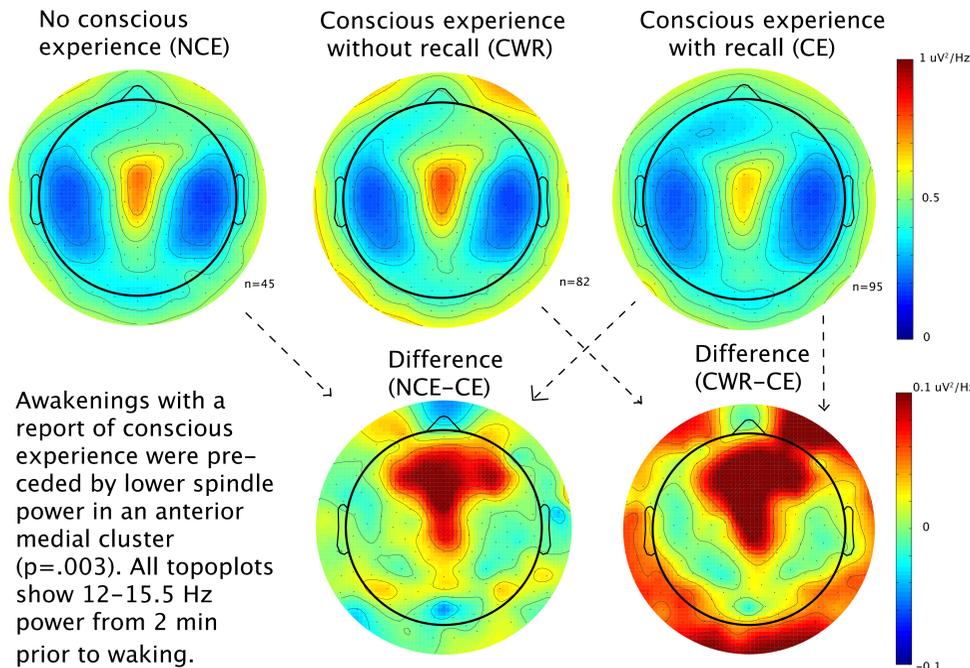
Methods

- Two healthy participants
- 16 overnight hd-EEG recordings (256 electrodes)
- 290 awakenings (222 in N2 and N3)
- Many awakenings, few subjects to account for interindividual variation in sleep consciousness and EEG
- Assessment of sleep consciousness – categories:
 - No sleep consciousness
 - Sleep consciousness without recall of content
 - Sleep consciousness with recall of content
- Assessment of richness and length of dream
- Time frequency transform of hd-EEG signal during two minutes preceding awakening
- Spindle detection algorithm for identification of individual sleep spindles²
- Multivariate pattern analysis (L2-regularized logistic regression) for EEG signal within sigma band (12–15.5 Hz)
- For spindle correlation analyses, an anterior medial ROI was used (purple in ROI schematic)

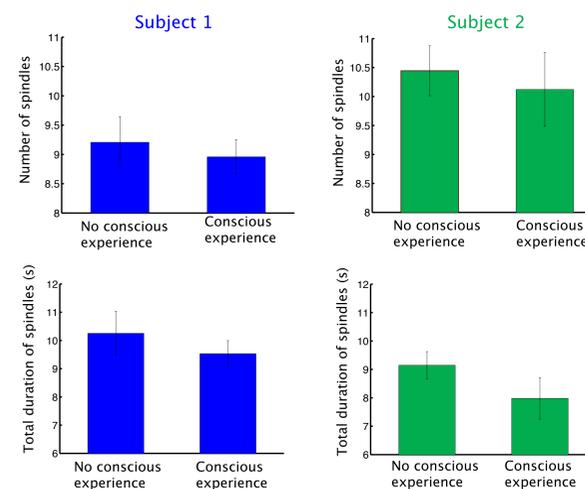


ROI schematic

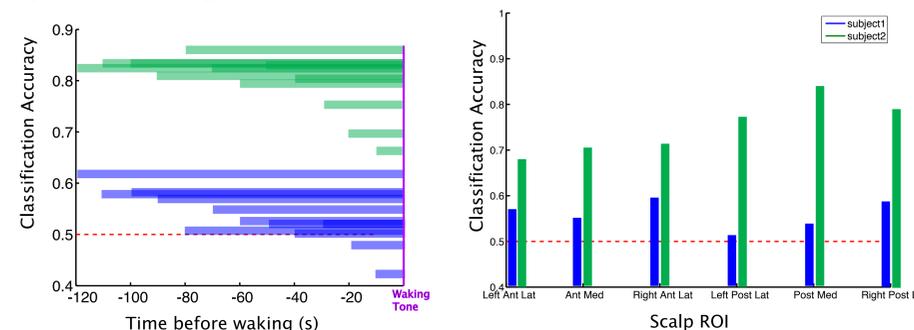
Sleep spindles are negatively associated with sleep consciousness



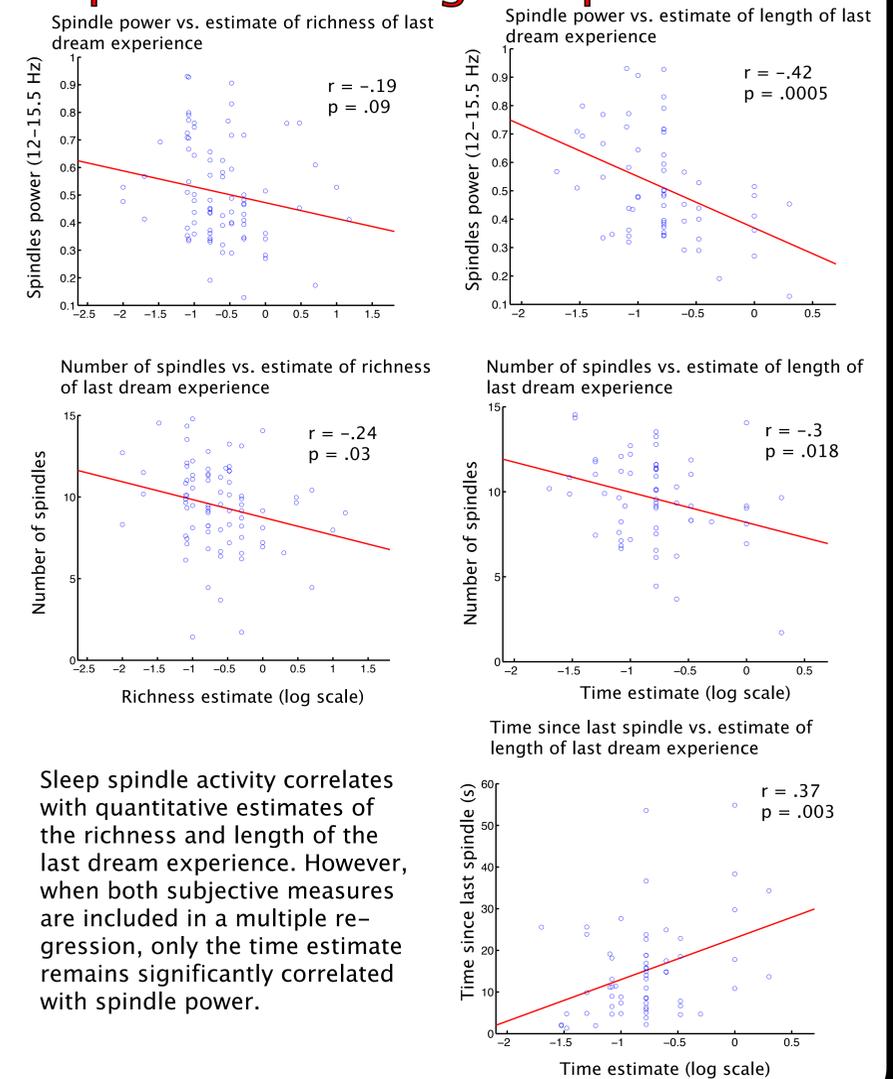
There is a non-significant trend in an anterior medial ROI for more spindles during sleep preceding a report of no conscious experience ($p = 0.08$). There is a similar, non-significant trend in total spindle duration ($p = 0.14$). Though these trends are non-significant, they agree qualitatively with the spindle power analyses above.



Initial results from MVPA of EEG spectral power in spindle range



Sleep spindles correlate with quantitative features of conscious experience during sleep



Conclusions

- The coordinated thalamocortical activity of sleep spindles disrupts the ability of the brain to generate consciousness during sleep
- The amount of sleep spindle activity is associated with subjective, qualitative characteristics of conscious experience during sleep
- Initial results of pattern classification indicate that classification is more successful with spindle power averaged over long durations

References

1. Tononi, G. Consciousness as Integrated Information: A Provisional Manifesto. *Biol Bull* 2008; 15(3): 216–242.
2. Ferrarelli F, Huber R, Peterson MJ, Massimini M, Murphy M, Riedner BA, Watson A, Bria P, Tononi G. Reduced Sleep Spindle Activity in Schizophrenia Patients. *Am J Psychiatry* 2007;164:483–492.