Spatio-temporal characteristics of correlated brain activity during awake rest and early sleep

M. Fukunaga[1], S. G. Horovitz[1], J. A. de Zwart[1], P. van Gelderen[1], S. C. Fulton[1], T. J. Balkin[2], J. H. Duyn[1]

[1]Advanced MRI, LFMI, NINDS, National Institutes of Health, Bethesda, MD, United States, [2]Department of Behavioral Biology, Walter Reed Army Institute of Research, Silver Spring, MD, United States

Introduction

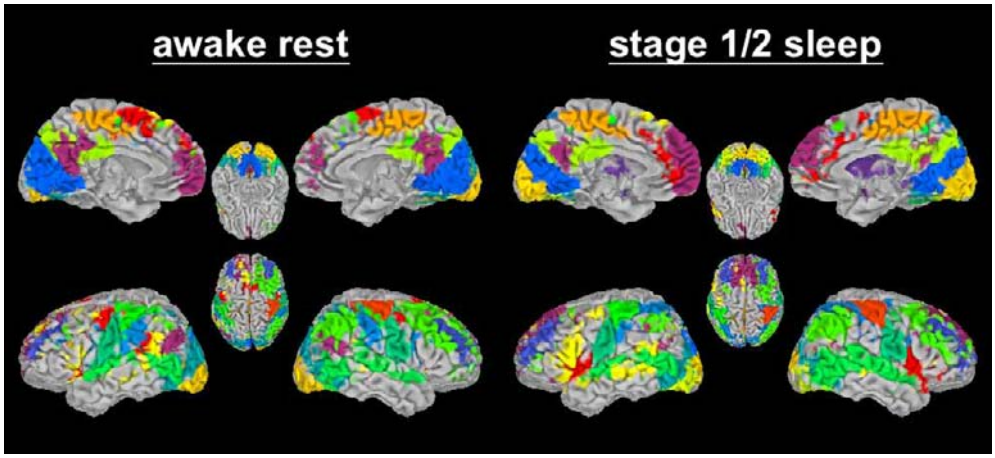
A number of recent BOLD fMRI studies have reported the presence of spatio-temporal patterns of correlated activity in the resting state. Measurements performed in absence of stimuli have shown temporal signal fluctuations that correlate within apparent functionally related regions. These correlations have been hypothesized to provide information about the "functional connectivity" of the brain [1,2]. However, it is unknown whether this spatially correlated activity represents conscious mentation. To investigate this, we performed BOLD fMRI during an extended resting state and early sleep while monitoring alertness using EEG.

Materials and Methods

Eleven normal volunteers, whose informed consent was obtained, participated in this study. Simultaneous fMRI (EPI, TR: 6 s, TE: 43 ms, spatial resolution: 1.7x1.7x3.5 mm^3, 28 slices, 600 volumes) and EEG (Synamps2 & Maglink, Compumedics) were collected on a 3.0T scanner (GE) with a 16 channel phased-array coil. Physiological monitoring (respiratory and cardiac cycles) was also performed. The experimental paradigm was composed of 50 minutes rest period, followed by 10 minutes visual task. During the rest period, the subjects were instructed to close their eyes and allowed to fall asleep. Cardiac rate, respiratory envelope and average time course of entire brain were used to regress out physiological noise and global signal changes. EEG datasets were visually inspected by a sleep expert (TJB) and each 30 s interval got scored as Wake or Sleep (Stage 1, 2 , SW or REM). To determine the wake and sleep epochs, a sliding average with 5 minutes window was applied to the original sleep score. Then, in order to detect and characterize spatio-temporal patterns of correlated activity, we applied spatial independent component analysis (ICA) to awake and sleep period separately, using MELODIC 2.0 (FSL3.2, FMRIB, University of Oxford [3]). After ICA, inter-subject consistency of ICs was evaluated by determining their spatial overlap after spatial normalization.

Results and Discussion

Seven of the 11 subjects showed a substantial amount of stage 1 and 2 sleep during the rest period. Eight subjects showed persistent awake state at least 10 consecutive minutes. During both awake rest and stage 1 and 2 sleep, we found a large number of ICs that involved almost exclusively gray matter regions. The total number of IC's during awake rest and sleep ranged from 33-84 (average 49.9 and 51.9 respectively). On the average, about 60% of the ICs showed spatial correlation in apparent functionally related regions (visual, sensory-motor, auditory and its' associate areas). The remaining 40% represented spike noise and spotty (random) noise, and motion related artifacts as apparent from a ring-like pattern around the brain periphery. We found 18 (awake) and 18 (sleep) ICs that showed a high spatially consistency across over each subject group (70% overlap within group) and resembled functionally connected regions. The temporal correlation between the IC time courses was low (average $r=0.02\pm0.02$) suggesting they are not the result of global physiological processes that modulate the BOLD signal. Frequency analysis of these IC time courses suggested that most energy was concentrated in the 0.01-0.1Hz band. The spatial extent and anatomical location of consistent ICs were very similar between awake rest and sleep. These results suggest that spatially correlated activity during rest is not specific to the awake state, and is therefore unlikely to represent conscious mentation.



Inter-subject consistency of ICs during awake rest, stage 1 and 2 sleep. *Different colors indicate the individual consistent IC's. Note that spatial extent and anatomical location of these consistent ICs is very similar between awake rest and sleep*

Conclusion

Accurate mapping of resting state activity patterns suggest an involvement of most brain regions that continues during sleep. This suggest that this phenomenon does not represent conscious mentation.

References

[1] Biswal, MRM 1995, [2] Greicius, PNAS 2003, [3] Beckmann, IEEE Trans Med Imaging 2004